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THE EFFECTS OF DISPLAY TYPE AND SPATIAL ABILITY

ON PERFORMANCE DURING A VIRTUAL REALITY

SIMULATION

by

Fernando Manrique

A Dissertation Presented in Partial Fulfillment
of the Requirements for the Degree
Doctor of Philosophy

ARIZONA STATE UNIVERSITY

August 1998

THE EFFECTS OF DISPLAY TYPE AND SPATIAL ABILITY

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SIMULATION

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ABSTRACT

The purpose of this study was to investigate the effects of display type and spatial ability level on performance during three trials of a virtual reality (VR) simulation. Seventy-six Air Force Reserve Officer Training Corps (ROTC) cadets were identified as having high or low spatial ability level. Subjects used either a helmet-mounted display or a standard computer monitor to perform a VR simulation. Assignment to either display type was counterbalanced by ability level. The study examined the effects of display type, spatial ability, and number of trials on simulation performance, performance strategy, discomfort level, display characteristics and attitude.

Results indicated that subjects with high spatial ability performed significantly better on the simulation than subjects with low spatial ability. Furthermore, performance results revealed a significant interaction between spatial ability level and trial. Separate analyses for each spatial ability group showed that the performance of high spatial ability subjects improved significantly from trial to trial. In contrast, the performance of low spatial ability subjects did not significantly improve over time. There were no significant performance differences between subjects that wore the head-mounted display versus subjects that did the simulation on a standard computer monitor.

Results for performance strategy suggested that high spatial ability subjects used more effective strategies during the simulation than low spatial ability subjects. Exploratory data analysis indicated that performance strategy was a stronger predictor of performance than spatial ability. Performance strategy accounted for 41% of the variance in performance scores, while spatial ability accounted for 13% of the variance explained.

Discomfort survey results indicated that subjects who used the head-mounted display reported significantly higher levels of cold sweating and difficulty focusing than subjects who used the standard computer monitor. Head-mounted display subjects also rated display resolution significantly lower than computer monitor subjects.

Results of this study contradict previous research on the benefits of practice for lower spatial ability subjects. High spatial ability subjects benefited significantly more from practice than low spatial ability subjects. Implications for organizations that require proficiency on spatial tasks and for the use of VR systems are provided.

DEDICATION

This work is dedicated to the cadets of AFROTC Detachment 025 at

Arizona State University

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I am very grateful to Dr. James D. Klein, my committee chair, for all his valuable guidance and advice. I would also like to thank the other members of my committee: Dr. Howard Sullivan, Dr. John Behrens, Dr. Raymond Kulhavy, and Dr. Wilhelmina Savenye. I am also very thankful for the assistance provided to me by Youngchun Park at ASU's Partnership for Research in Simulation and Modeling. Colonel Gorman, Commander of ASU's Air Force ROTC detachment, also has my appreciation for allowing me to conduct my study with his cadets and in his facilities. Finally and most importantly, I would like to thank my wife Kathy and my daughters Adriana and Liliana for giving me the perspective necessary to complete this work.

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CHAPTER I

INTRODUCTION

In recent years, trainers have been interested in the use of Virtual Reality systems to teach complex tasks. The advent of powerful computers provides the ability to re-create reality for training purposes. However, there are a number of questions about the use of Virtual Reality systems in training. It is not clear if these systems require the use of head-mounted displays (HMDs) or even if there are side effects inherent in the use of HMDs that might negate any potential advantages. In addition, it is not certain if all students can learn effectively when using these systems.

Because Virtual Reality is in a relatively early stage of development, there are few answers to the questions posed by their use in training. For example, some experts suggest that HMDs are an essential element of a Virtual Reality system, while others indicate that virtual reality is a psychological phenomena and that HMDs are not essential to achieve the training effects of presence or immersion (Moshel & Dunn-Roberts, 1996).

Research on the use of HMDs could assist trainers in determining the most effective and cost efficient ways of using Virtual Reality. Since most training organizations have limited amounts of funding, cost is an important consideration. The difference in cost between a Virtual Reality training platform delivered with HMDs versus one delivered

using standard computer monitors can be staggering. A state-of-the-art Virtual Reality package featuring a head-mounted display and a DataGlove as user interface can cost approximately $205,000, while a top-of-the-line desktop platform would cost approximately $5,000 (Franchi, 1995). Research on the effectiveness of delivery platforms would provide a basis for making decisions about Virtual Reality.

The following paragraphs explore the basic elements of Virtual Reality systems and research conducted on its effectiveness as a training platform. In addition, some of the literature on individual differences in spatial ability will be reviewed, particularly as it applies to the acquisition of complex spatial skills. Finally, several of the research studies conducted for the Learning Strategies Project will be discussed.

Virtual Reality

According to Stashower (1990), the first concepts about what has become known as Virtual Reality can the attributed to Hugo Gernsback, who as early as the 1930's had developed a head-mounted television set and the "Isolator", a helmet-like device intended to filter out distractions and promote pure thought. A few decades later, Ivan Sutherland (1965) described "a display connected to a digital computer (to) give us a chance to gain familiarity with concepts not realizable in the physical world" (pp. 506, 508). It was Sutherland who coined the term "ultimate display" to describe what we know today as Virtual Reality (VR) systems (Biocca et al, 1995).

VR systems in existence today share at least three attributes (Kalawski, 1993). The first attribute is presence, which is a sense of belief in one's real existence in the simulation. This can be achieved by viewpoint manipulation, such as viewing the simulation from "inside" of the craft or instrument being utilized. Another way to

achieve presence is by being able to see one's virtual hands and body in the simulation. The sense of presence is also enhanced when there is a consistent way of interacting with the objects in the virtual world.

The second attribute is interaction, or the ability to change features of the virtual world in a natural fashion. When objects can be manipulated in real time during a simulation, a program is considered to have a high degree of interaction. Delays between the operator's input and an object's response hinder interaction. Modern graphics computers allow for high degrees of interaction.

The third attribute of VR systems is autonomy. Virtual objects that have the ability to react independently and in response to the operator's input are said to be autonomous. Autonomy is very difficult to achieve, but extremely important (Kalawsky, 1993).

Even though the concepts of *interaction* and *autonomy* are important, these are more technical in nature and pertain more to hardware and software considerations than to education and training issues. The sense of *presence* is the characteristic of Virtual Reality systems that can be most important from a trainer's standpoint.

Presence is what makes a participant feel immersed in the experience (Biocca & Delaney, 1995; Kalawsky, 1993). In VR systems, visual and aural cues are used to engage the sense of presence. Extended periods of immersion lead to adaptation and a sense of complete presence. A breakdown in the sensation of virtual presence occurs when the person feels tired or when the weight of the head-mounted display becomes uncomfortable. Unnatural movements or lags in the virtual environment can also lead to conflicts in the feeling of presence, but if the participant is stimulated with visual and

auditory information of high fidelity and is allowed to interact with objects in the virtual environment, the feeling of presence can be very powerful (Kalawsky, 1993).

Biocca & Delaney (1995) have constructed a classification table in order to clarify the different levels of immersion and consequently the varying levels of presence that can be attained with Virtual Reality systems. This classification scheme is presented below:

A classification of virtual reality systems (Biocca & Delaney, 1995).

Types	Description
Window systems	A computer screen provides a window into an interactive 3D world.
Mirror systems	The users look at a projection screen and see an image of themselves moving in a virtual world.
Vehicle-based systems	The user enters a simulated vehicle (i.e. tank, airplane) and operate controls that simulate movement in a virtual world.
Cave systems	User enters a room or enclosure where they are surrounded by a virtual scene.
Immersive VR systems	Users wear displays that fully immerse a number of the senses in computer generated stimuli.
Augmented reality systems	Users wear a visual display that superimposes 3D virtual objects on real-world scenes.

According to Biocca & Delaney (1995), level of immersion appears to exist in a continuum, from the Window systems of a standard computer display to the fully immersive systems of HMDs and Augmented Reality systems. Whether this continuum would correspond to changes in the performance of participants has yet to be determined.

Unfortunately, there are only a few research studies that deal with presence and there is little agreement as to what amount of presence is required to train effectively in a

virtual environment. Calvert & Lan-Tan (1994) found physiological differences in subjects that actively participated in a violent Virtual Reality game versus participants that merely observed the game, concluding that the feeling of immersion was more pronounced on the active participants and consequently affected them more than the observers. In her study with autistic children, Sutherland (1993) found that subjects who used a fully immersed HMD accepted the VR representation of reality (sense of presence) as another real world by interacting autonomously with the virtual environment.

In the field of education, the most ambitious work on Virtual Reality for educational purposes has revolved around a university/government project called Science Space (Dede et al., 1997). Three virtual worlds have been developed to test the effects of immersion (presence) on learning topics in science. Even though results are preliminary, data suggests that students can improve mastery of abstract science concepts such as Newton's Laws of Motion with the use of immersive VR equipment.

There have been a few studies on the use of Virtual Reality systems to train for certain kinds of navigational tasks. McCormick & Wickens (1996) investigated the effects of level of immersion (point of view) and stereopsis (2D versus 3D) and found that the level of immersion can have positive effects for specific tasks but negative effects for other tasks. When subjects were required to travel from one point to another in virtual space, a fully immersed point of view was significantly better than a less immersed point of view. However, when the task involved global overall judgements, the less immersed point of view proved superior. In all cases, however, a 3D display was always significantly better than a 2D display. Bliss & Tidwell (1997) trained firefighters on how to navigate

through unfamiliar buildings during a fire response. They found that firefighters were as effective using a 3D virtual representation of a building as when studying building blueprints in completing the task of learning a building's layout. A similar navigational study by Regian & Shebilske (1992) investigated the effects of traveling in a 3D VR maze versus a 2D display and found the VR subjects were quicker at learning the maze, as evidenced by their faster navigation times.

Some researchers have attempted to test for specific characteristics of presence. Slater and Usoh (1993) found that the sense of presence could be affected by an individual's "startle response" to a sense of danger. Subjects that were involved in tasks that required rapid reactions to perceived threats reported higher feelings of immersion over those involved in less stimulating tasks. Henry and Furness (1993) had subjects stroll through a virtual art gallery and them asked them to make estimations about the gallery's length, width, and height. He found that distances in virtual environments are perceived as smaller than actual distances and attributed this to the truncated field of view of current head-mounted displays.

There are recent studies on the effectiveness of Virtual Reality in actual training tasks (Delp et al., 1997; Loftin & Kenney, 1997; Satava & Jones, 1997). One worth noting comes from the National Aeronautics and Space Administration (NASA) (Loftin & Kenney, 1997). In preparation for the Hubble Space Telescope repair mission, over 100 members of the NASA ground crew repair team received 200 hours of training using Virtual Reality equipment. VR allowed earth-bound technicians to "travel" to low earth orbit and design the procedures required to repair a satellite in orbit. Results indicated that VR training enhanced job performance for most participants during the actual repair

mission. Another study investigating the effectiveness of VR to train surgeons in surgical skills with the use of a VR simulator was inconclusive (Johnston et al., 1997). Results indicated that use of the VR simulator did not significantly affect the performance of surgeons. Researchers concluded that the costs of the equipment were still prohibitive and VR performance did not justify the development efforts required.

A number of studies have found that there are side effects to the use of head-mounted displays in virtual reality training systems (Dede et al., 1997; Kolasinski, 1995; Manrique et al., 1997; Moshell et al., 1993). Moshell et al. (1993) reported that most participants indicated some type of "simulator sickness" after accomplishing a virtual object tracking and manipulation exercise. Manrique Sullivan and Klein (1997) found that about 70% of participants reported mild to high levels of visual discomfort after performing an object rotation task wearing a head-mounted display. Preliminary results from the Science Space project (Dede et al., 1997) also indicate that several participants suffered from difficulties such as eye strain that interfered with their performance. Clearly, how HMDs physically affect users is an area of potential concern to the researcher interested in the utility of VR as a training platform.

While studies have been conducted on the utility of VR, it is still not clear if these systems are an effective tool for training. Biocca et al. (1995) suggested that "VR has yet to be proven and most systems still have the feel of prototypes. There is a lack of objective measures of performance. Research must be conducted on all aspects of virtual environment systems that have a possible bearing on participants performance" (pg. 13).

Spatial Ability

Virtual environments, with their capacity to aid in the "visualization" of three-dimensional objects, may affect the performance of individuals with lower so-called spatial skills. Furthermore, researchers investigating spatial ability have been quick to utilize the visualization capabilities of modern display platforms in their studies. This is because computers and VR systems are well suited to handle the type of graphics required to create the 3D rotation in space images of most spatial tasks (Greenfield & Lohr, 1994; Shah & Miyake, 1996; Shepard & Metzler, 1971).

A lot of attention has been focused on the notion of individual differences in spatial abilities. Many variables have been explored to explain how these differences occur in individuals. These have included left or right handedness, gender, ethnicity, and life experience (Acredolo, 1981; Birembaum et al., 1994; Calvert & Lan-Tan, 1994; Okagaki & Frensch, 1994).

Recent studies suggest that differences in spatial ability might not be fixed but can be manipulated through practice (Subrahmanyam & Greenfield, 1994). This would imply that there might not be any inherent differences in the spatial skills of individuals, but only in their level of spatial experience. A few studies seem to suggest that given enough experience, lower spatial ability subjects can benefit more from practice than higher spatial ability subjects (Gopher et al., 1989; Hays, 1996; Subrahmanyam & Greenfield, 1994).

In the Subrahmanyam and Greenfield study (1994) subjects were pre-tested with a standard spatial ability measure and were then given 2.5 hours of experience on a computer based game. The study indicated that after exposure, spatial ability posttest

scores were significantly higher for all subjects; however, lower spatial skill subjects benefited more from the experience than higher spatial skill subjects. Gopher et al. (1989) found that increases in spatial ability could be attributed to the use of strategies instead of length of practice. Providing lower ability subjects with proven performance strategies was enough to raise their performance levels to near those of higher performers with no strategy training. In the Hays study (1996), lower spatial ability subjects receiving computer animation feedback made significantly greater gains in performance over lower ability subjects not receiving animation.

The implication of these findings could be important to institutions such as the military that use static determinations of spatial ability as job selection criteria. If spatial ability is affected by such factors as practice or strategy use, then findings of individual differences in spatial skills become less important. Research should focus instead on how to influence spatial ability for complex spatial tasks such as those investigated in the Learning Strategies Program project.

<u>Learning Strategies Program</u>

The Learning Strategies Program was a research project conducted at the Cognitive Psychology Laboratory (CPL) of the University of Illinois. The main emphasis of the research was the study of complex skill and its acquisition. The goals of researchers were (1) to create a complex task that was representative of real life tasks, (2) to incorporate dimensions of difficulty that were of interest based on existing research on skill and its acquisition, and (3) to keep the task interesting and challenging for the subjects during extended practice (Mane & Donchin, 1989). A number of studies were conducted under this project (Fabiani et al., 1989; Foss et al., 1989; Gopher et al., 1989; Lintern, 1989;

Rabbitt et al., 1989; Shapiro & Raymond, 1989), coordinated by the CPL but involving a number of other institutions here and abroad.

The primary research tool utilized in the Learning Strategies Program was a space combat computer game developed exclusively as a research tool for this project named Space Fortress. The game had subjects operate a space ship and engage in combat with a large enemy space fortress. A number of variables were studied and measured, including spatial ability levels, practice effects, and performance strategies.

Gopher and Weil (1989) found that lower ability subjects benefited more from structured practice with Space Fortress than higher ability subjects. They concluded that lower ability subjects have only limited knowledge of their resources and make little effort in exploring different approaches to problem solving. However, given proper guidance, their performance came very close to the level of high performers without guidance.

Another study looked at the correlation between standard measures of spatial ability and performance on an actual spatial skill. The study indicated that performance in Space Fortress could be more readily predicted with an IQ test than with standard measures of spatial skills or even measures of prior video game experience (Rabbitt & Banerji, 1989).

Shapiro and Raymond (1989) used Space Fortress to research the effects of training psychomotor strategies to increase performance in spatial tasks. In this study, subjects were taught efficient eye movement training (optimal scanning versus no eye pattern training). These researchers found significant performance increases for trained subjects.

The Learning Strategies Program demonstrated the utility of computer simulation games as a vehicle for use in complex spatial skills acquisition studies. By today's standards, however, Space Fortress would seem rather primitive. Graphics consisted of simple line figures with no color and limited sound. Recently, one of the original Space Fortress developers (Donchin, 1995) stated that he would have been delighted if he could have used current color displays with all the images in 3D and with stereo sound. He suggested that the realism might have kept subjects even more motivated than they appeared to be in the original series of studies.

An updated version of Space Fortress was utilized for a series of studies (Regian & Shebilske, 1993; Shebilske & Regian, 1992) in order to investigate whether there were significant differences between the newer version and the original version of Space Fortress. Results indicated no significant differences in performance between versions.

Donchin's desire for a space combat game in full color with stereoscopic imaging and stereo sound has been made possible by advances in computer graphics design. VR Space Duel, a program developed as a demonstrator for PC deliverable virtual reality, maintains the original Learning Strategies Program research goals. Those goals were creating a complex task representative of real life tasks, incorporating dimensions of difficulty of interest based on existing research on skill and its acquisition, and challenging subjects during extended practice.

VR Space Duel is a fully immersive system that requires a helmet-mounted display (HMD) and a joystick interface. Research using Space Duel as a tool will help determine the effects of using HMDs in training complex spatial tasks with subjects who have different spatial ability levels.

Purpose of this study

The purpose of the current study was to investigate the effects of display type and spatial ability on performance during a complex Virtual Reality simulation. The major independent variable of interest was display type (Head-Mounted Display versus Monitor). Most Air Force flight training instruction is currently being taught via some form of computer delivery (CBI). With the lower costs associated with computer display capabilities, Virtual Reality (VR) systems are coming on-line for use in training. These virtual systems offer varying levels of immersion. The most immersive are those utilizing head-mounted displays (HMDs). The training utility of these VR systems and their HMDs has not been fully explored. Determining their utility in accomplishing certain kinds of complex spatial tasks might be useful in flight selection screening or flight training.

The second independent variable of interest was spatial ability level (High versus Low) as defined by a standardized paper and pencil spatial ability measure using Vandenberg's Mental Rotations Test (Peters et al., 1995). Of major interest were differences in levels of spatial ability as they related to learning complex spatial skills and how these differences related to strategies utilized by learners in accomplishing difficult spatial tasks. In US Air Force pilot screening and training, spatial ability, as measured by standard paper and pencil tests, is considered a key ingredient in the potential for a pilot candidate to succeed in a flight-training program.

An additional independent variable of interest was the effect of practice (trial one, trial two, trial three) on performance. It was deemed important to determine how practice affected a subject's performance of a complex spatial task and whether different

platforms could have similar effects over several trials. Furthermore, the effect of practice on the performance of learners with different levels of spatial ability was explored.

The main dependent variables were performance of a complex Virtual Reality space-flight combat simulation measured by number of enemy ships destroyed and overall performance strategy utilized. Additional dependent measures included a simulation discomfort rating (Lane & Kennedy, 1988) and attitude. The simulation was a prototype version of the VR Space Duel space-combat research tool. The main objective in the simulation was to shoot and destroy an enemy in a one-to-one duel. Shots were fired from an aircraft whose movement was controlled by each subject. In addition to destroying the enemy ship, the subjects had to constantly maneuver to protect their craft against counter-attack by the target.

The major research questions addressed in this study were:

1. What is the effect of display type on the performance, attitudes, and en-route behavior of subjects accomplishing a complex Virtual Reality space-combat simulation?
2. What is the effect of spatial ability level on the performance, attitudes, and en-route behaviors of subjects accomplishing a complex Virtual Reality space-combat simulation?
3. What is the effect of practice on the performance, attitudes, and en-route behaviors of subjects accomplishing a complex Virtual Reality space-combat simulation?
4. How will display type interact with spatial ability level and practice to affect performance, attitudes, and en-route behaviors of subjects accomplishing a complex Virtual Reality space-combat simulation?

5. How will strategy use affect the performance of subjects accomplishing a complex Virtual Reality space-combat simulation?

This study was conducted at an Air Force Reserve Officer Training Corps (AFROTC) detachment of a large southwestern university. Because the treatment population was representative of the overall Air Force officer population, findings will be useful to a number of military and civilian researchers in the areas of education and training.

CHAPTER II

METHOD

Subjects

Seventy-six subjects from Arizona State University's Air Force Reserve Officer Training Corps (AFROTC) program participated in this study. Subjects were all enrolled in the local AFROTC curriculum and were to become Air Force officers upon successful graduation. Since they had not been pre-screened for flight training eligibility, levels of spatial ability in the subject population, as determined by Vandenberg's Mental Rotations Test, were similar to their general age group population (ASU AFROTC M = 23.829, SD 4.40, General Population Age 19 M = 21.05, SD = 5.50). The ASU AFROTC population was 85% male and their average age was 19.

Materials

A Virtual Reality interactive space simulation entitled VR Space Duel was the source of instruction for this study. VR Space Duel was originally developed by Ixion Inc. as a personal computer (PC) based virtual reality demonstrator. The simulation used in this study was a prototype version of the original VR Space Duel simulation configured for delivery by either a head-mounted display platform or using a standard computer monitor.

The VR Space Duel simulation maintained the original goals of the Learning Strategies Program research project. VR Space Duel was a complex task that is representative of real-life highly spatial tasks, it incorporated dimensions of difficulty that are of interest based on existing research on skill and its acquisition, and it kept the task interesting and challenging for subjects during extended practice (Mane & Donchin, 1989).

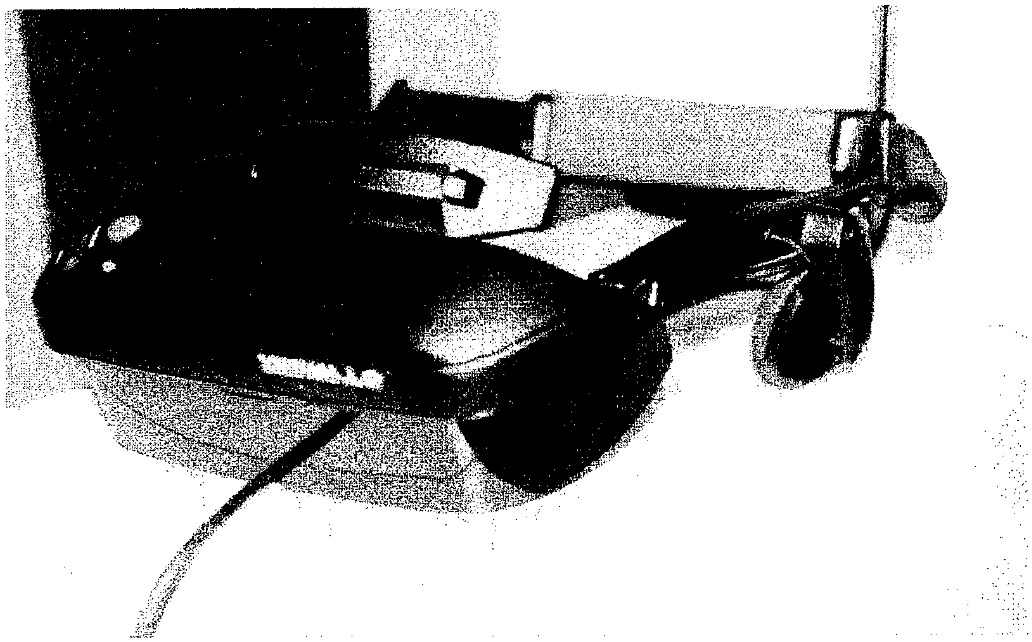
There were two levels of treatment. One group accomplished the simulation while wearing a Head-Mounted Display (HMD) and the other group accomplished the simulation using a standard computer monitor. Figure 1 shows a view of the HMD as well as the standard computer monitor configuration.

The Helmet Mounted Display group utilized a *Virtual I/O* head-mounted display weighing approximately eight ounces. The HMD consisted of two full-color liquid crystal displays (LCDs) in a heads-up configuration with a resolution of 180,000 pixels per LCD. Each LCD presented a 30-degree field of view in each eye, with 100% stereo overlap and a 11' fixed focus designed to minimize eye strain. The system also included a three degree-of-freedom Head Tracking Unit (HTU). The interface with the computer was accomplished using a *Super Warrior* joystick flight control interface that was operated by the subject (Figure 2). The joystick operated the ship's thrusters (forward and reverse), the firing trigger for the spaceship's guns, as well as directional control of the ship.

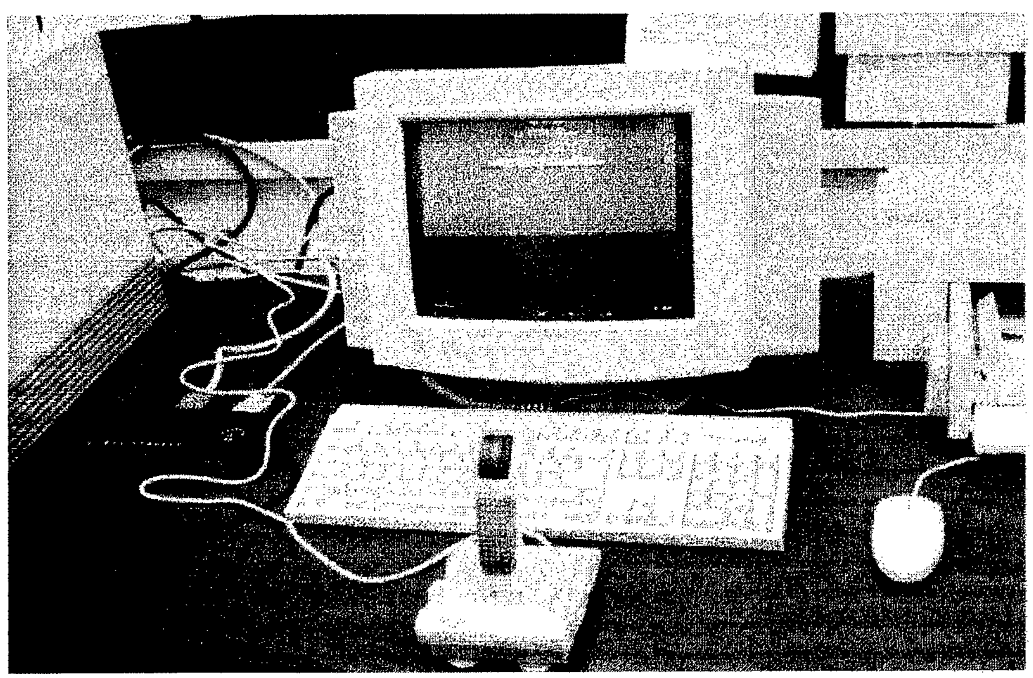
The computer monitor group accomplished the simulation using a standard 14 inch computer display monitor with a resolution of 400,000 pixels. Subjects utilized the same

Figure 1.

Head-Mounted Display and Standard Computer Monitor



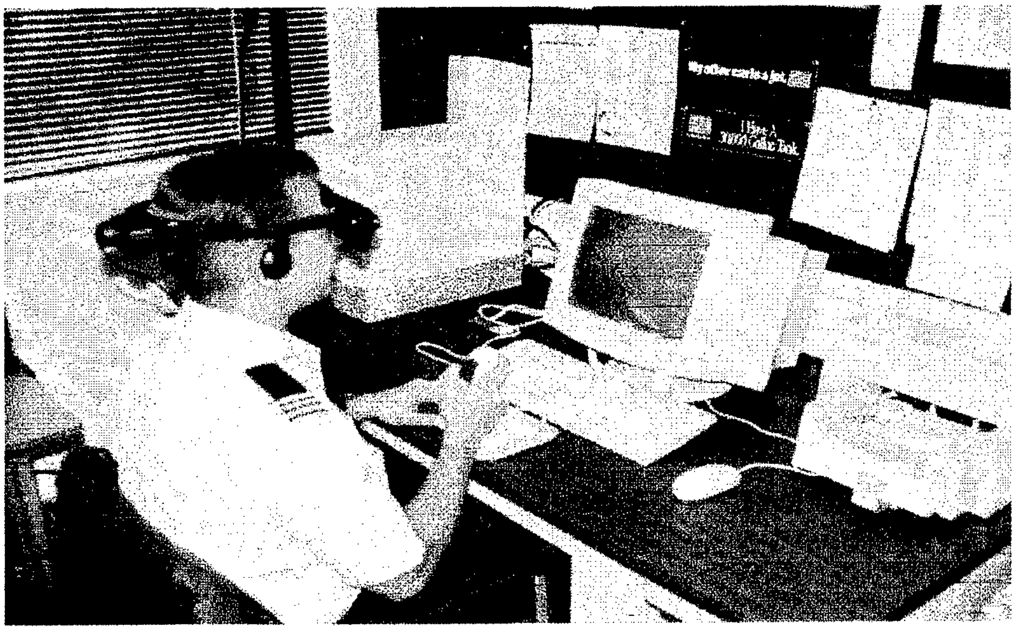
Virtual I/O Head-Mounted Display



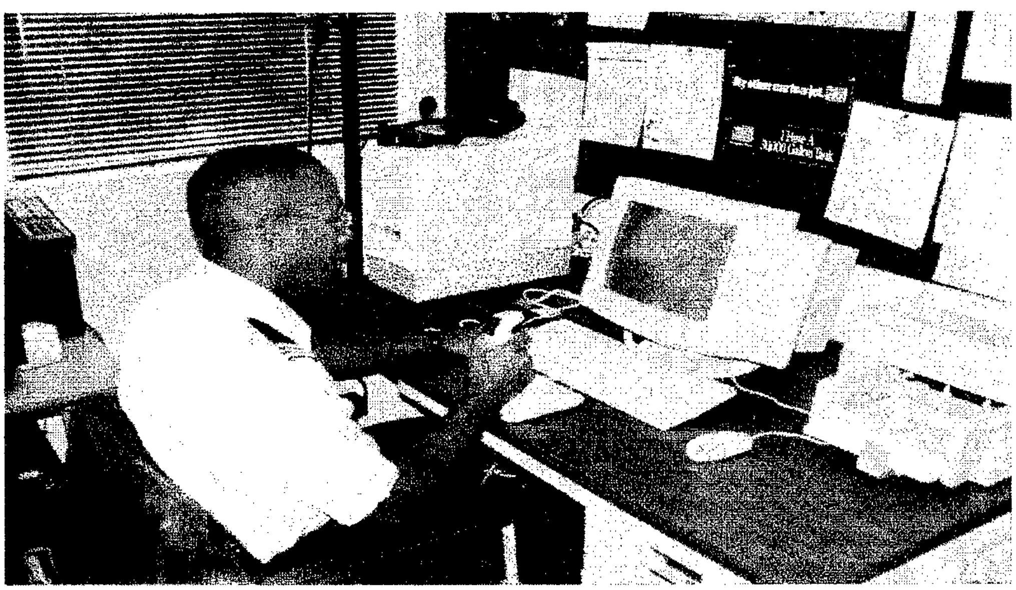
Standard Computer Monitor

Figure 2.

Joystick Interface with Head-Mounted Display and Standard Computer Monitor



Helmet-Mounted Display with joystick interface.



Standard computer monitor with joystick interface.

Super Warrior joystick interface to aim, fire, and operate the thrust jets as the Head-Mounted Display group. The treatments were otherwise identical.

The object of the VR Space Duel simulation was to shoot at and destroy an enemy aircraft in a one-to-one space duel. Shots were fired from a ship controlled by the subject using the joystick as the primary interface. In addition to destroying the enemy ship, the subject had to protect his ship against damage from counterattacks by the opposing ship.

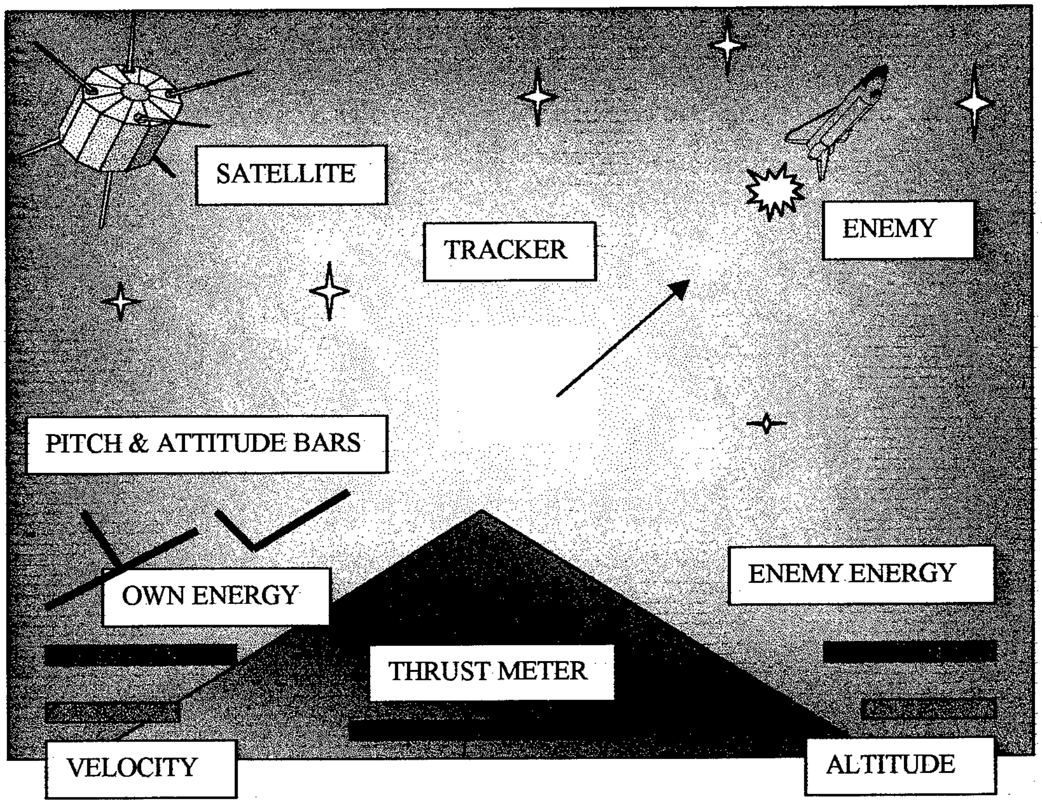
Due to the difficulty of the simulation, the program variables were preset to allow the participants a 50% power advantage over the opposing ship. There was also a preset 50% energy efficiency gain, which caused the enemy ship to expend 50% more energy than the subject's ship. These preset factors were required to allow subjects of all spatial ability levels to achieve some success in the simulation.

The primary mission in the simulation was to shoot and destroy the enemy ship in successive one-to-one encounters. Shots were fired from the aircraft controlled with the joystick interface. In addition to destroying the enemy ship, subjects had to attempt to conserve as much energy as possible. Both participant and the enemy had a finite amount of available energy. To win, participants had to either destroy the enemy craft with guns or cause him to expend his energy before their own ran out.

Participants could also activate an enemy-tracking device by pressing on the "T" letter key on the computer keyboard. The tracking device gave them real-time updates as to the relative direction of the opposing ship. It was also color coded to indicate whether the dueling craft was in a forward or rear quadrant. Figure 3 depicts a typical screen illustration.

Figure 3.

VR Space Duel Illustration



Sample internal perspective view

Subjects could also elect to switch their outside viewing perspectives by pressing on the computer's space bar. There were three different "outside" perspectives that could be selected. The first one gave them an internal cockpit view as if they were flying inside the ship's cabin. The second perspective was an external chase view, as if they were seeing the action from a camera placed directly behind their ship. The third perspective was a fixed external view. The fixed external view showed both spaceships from a God's eye perspective.

In the course of destroying the enemy craft, participants had to overcome a number of obstacles. First, the enemy defended itself against attack. It did this by rotating to face their ship, and then trailing their ship's movements while firing shots at it. If participants failed to take evasive action, the enemy craft would run into their ship and damage it or simply destroy it with his guns. The enemy ship also constantly maneuvered to avoid being attacked, and utilized existing physical obstacles to hide from attacks.

Whenever the enemy spacecraft hit a participant's ship, it was damaged. When the ship was damaged for the third time, it was destroyed and the simulation would restart with a brand new encounter. Subjects' scores were computed and displayed after each engagement. The score screen showed who was victorious and how long each engagement had lasted. After a complete trial, the score indicated total number of victories as well as number of defeats. Subjects could also check their performance by looking at the status bar on the bottom part of the screen. There they found both their own and their opponent's energy level as well as their ship's altitude, velocity, and attitude relative to the horizon.

Procedures

Prior to the simulation, all subjects were initially tested for spatial ability using Vandenberg's Mental Rotations Test (MRT). The overall spatial ability mean for the sample population was M = 23.829 (SD = 4.40). Subjects scoring above the median (Md = 24) were categorized as high spatial and those scoring below the median were categorized as low spatial. This resulted in two groups of 38 subjects each. Subjects scores on the spatial ability pretest by category were M = 30.21 (SD = 4.21) for the group categorized as high spatial (ranging from 24 to 40) and M = 17.44 (SD = 5.00) for the group categorized as low spatial (ranging from 7 to 24).

All pretest spatial ability scores were rank ordered and subjects assignment to each of the two treatments (HMD/computer monitor) was counterbalanced by spatial ability level. They were then scheduled for individual treatment sessions.

On the day of the simulation, all subjects were given a brief handout with instructions on how to accomplish the simulation. The handout detailed the main objective of the VR Space Duel mission as well as the weapons available to them. It also described the enemy spaceship's tactics and weapons. Participants were then given instructions on how to operate the hand-held *Super Warrior* joystick interface. The brief training and familiarization period (5 minutes) included how to operate the thrust controllers, general maneuvering, and aiming and firing guns. For those in the Helmet-Mounted Display group, training also covered how to fit and adjust the *Virtual I/O* HMD.

After equipment familiarization, the HMD treatment group accomplished the simulation wearing the Virtual I/O Head-Mounted Display and Super Warrior joystick interface. Subjects had three fifteen-minute trials, with each trial followed by a ten-minute rest period, for a total of 45 minutes of actual engagement. During each rest period, subjects completed a simulator discomfort survey (SDS). Performance scores were tracked for each trial and an overall score was computed at the end. An observer also recorded strategy use at the completion of each trial using a performance strategy template.

The monitor treatment group accomplished the simulation from a standard desktop computer monitor. Subjects used an identical Super Warrior hand-held joystick interface to maneuver, aim, and fire as the HMD group, but did not wear the Helmet-Mounted Display. Subjects also had three fifteen-minute trials each followed by a ten-minute rest period for a total of 45 minutes of simulation. During each rest period, subjects also completed a simulator discomfort survey (SDS). Scores were tracked for each trial and an overall score was computed at the end. An observer also recorded strategy use for each trial using the performance strategy template.

Subject's primary objective in both treatment groups was to maximize their score by winning the greatest number of duels in each of the three trial periods. The secondary objective was to constantly maneuver to avoid destruction by the enemy ship.

Upon completion of the third and final trial and the final Simulator Discomfort Survey (SDS), subjects evaluated the properties of their respective display platforms by answering a Display Evaluation Questionnaire (DEQ). Finally, a short attitude survey was given to gage overall attitudes towards each treatment.

Criterion Measures

The primary dependent measure was performance, defined as number of enemy ships destroyed. A secondary dependent measure was performance strategy utilized. Additional dependent measures included a simulator discomfort survey (SDS) to determine physiological side effects of different VR display types, a display evaluation questionnaire (DEQ) to evaluate display characteristics, and an attitude survey to determine subject attitudes towards respective treatments.

The primary criterion measure was the number of enemy ships destroyed since this was the primary objective of VR Space Duel. To be successful in destroying the enemy ship, subjects had to master the complex spatial and psychomotor requirements of the simulation. En-route behavior was measured by tracking performance scores during each of the three trials and computing a per-trial and a global score. Tracking individual trial scores was done to help determine practice effects on performance. The test-retest reliability of the performance measure was $r = .83$.

Performance strategy was determined by direct observation of the subject's aircraft maneuvering and joystick manipulation patterns. The experimenter used a template that categorized strategy used into one of three major ship maneuvering patterns (Foss et al., 1989): (1) Slow circling, (2) Rapid circling, and (3) Straight-line flight. Subjects using the Slow Circling flight pattern were characterized by small manipulation inputs to the joystick and slow ship movement across the screen in all dimensions. Rapid Circling was characterized by large and abrupt control inputs in all dimensions, resulting in frequent overshooting of the intended target. Straight-line flyers were characterized by little

manipulation of the thrusters, maintaining an initial straight-line directional input, and being concerned only with controlling rotation.

Simulation side effects for each display type were measured using a Simulator Discomfort Survey (SDS)(Lane & Kennedy, 1988). The questionnaire was completed three times by each subject during the rest periods after each of the fifteen-minute performance trials. The SDS generated a general discomfort rating that was measured for each trial as well as overall. The test-retest reliability of the SDS was .82.

General display effectiveness was measured with a Display Effectiveness Questionnaire (DEQ)(Serfoss, 1992) that was included in the end-of-experiment attitude survey. The DEQ provided a measure of effectiveness for each of the display types. Questions related to image clarity, resolution, and color. The DEQ score permitted display effectiveness comparisons between platforms.

As a final dependent measure, subjects were given a ten-item post experiment questionnaire. There were questions on attitudes towards immersion, relevance, and general feelings towards the treatment. A Likert-type scale was used to collect attitudinal responses. The Cronbach Alpha reliability of the attitude survey was .71.

Design

This study used a 2 X 2 X 3 repeated measures design. The independent variables were display type (Head-Mounted Display versus standard computer monitor), spatial ability level (high spatial versus low spatial), and trial (trial one, trial two, trial three). The dependent variables were performance (number of enemy ships destroyed), performance strategy utilized, simulator discomfort rating, display characteristics and

attitude. Display type and spatial ability were between-subjects variables. Trial was a within-subjects variable.

Data was analyzed using a 2 (display type) X 2 (spatial ability) X 3 (trial) repeated measures analysis of variance (ANOVA) for performance (number of enemy ships destroyed). Performance by spatial ability groups was also analyzed separately using a 2 (display type) X 3 (trial) repeated measures ANOVA. Performance by individual trial was analyzed using a 2 (display type) by 2 (spatial ability) analysis of variance. Stepwise multiple regression was used to analyze the effects of performance strategy on performance score. Simulation discomfort, display characteristics, and attitude data were analyzed by using separate ANOVA's on each individual questionnaire item. Alpha was set at .01 due to the number of statistical tests.

CHAPTER III

RESULTS

The results are reported below for five main variables. These variables include performance, performance strategy, simulation discomfort index, display characteristics, and attitude.

Performance

Means and standard deviations for performance as measured by number of enemy ships destroyed are reported in Table 1. The data revealed that the mean number of ships destroyed per trial was 6.3 (SD = 2.3) for high spatial ability subjects and 4.6 (SD = 2.4) for low spatial ability subjects. Table 1 also shows that the mean overall score by display type was 5.3 (SD = 2.4) for the helmet-mounted display (HMD) group and 5.6 (SD = 2.6) for the standard computer monitor group. The overall means per trial were 5.0 (SD = 2.6) for trial one, 5.5 (SD = 2.5) for trial two, and 5.8 (SD = 2.5) for trial three. The mean number of ships destroyed for all subjects was 5.4 (SD = 2.4).

Table 2 provides an analysis of variance (ANOVA) summary table for performance scores. ANOVA indicated that subjects with high spatial ability performed significantly better (i.e. destroyed more enemy ships) than those with low spatial ability, $F(1, 72) = 10.977$, $p = .001$. ANOVA also indicated that subjects performance improved

Table 1

Number of Enemy Ships Destroyed per Trial

	Trial One		Trial Two		Trial Three		
	HMD	Monitor	HMD	Monitor	HMD	Monitor	Total
Hi Spa.	5.3	5.8	6.3	6.5	7.0	7.2	6.3
SD	2.4	1.8	2.4	2.1	2.5	2.6	2.3
Lo Spa.	4.3	4.8	4.5	4.7	4.5	4.8	4.6
SD	2.0	3.6	2.5	2.6	1.7	2.0	2.4
Total	4.8	5.3	5.4	5.6	5.7	6.0	5.4
SD	2.2	2.8	2.6	2.5	2.5	2.6	2.4

Overall Means

Hi Spatial = 6.3	HMD = 5.3	Trial One = 5.0
Lo Spatial = 4.6	Monitor = 5.6	Trial Two = 5.5
		Trial Three = 5.8

Table 2

ANOVA Summary Table for Performance Scores

Source	SS	DF	MS	F-Ratio	P
Spatial Ability	170.215	1	170.215	10.977	0.001*
Display Type	5.373	1	5.373	0.346	0.558
Trial	25.509	2	12.754	10.243	0.000*
Ability by Display	0.039	1	0.039	0.003	0.960
Ability by Trial	20.667	2	10.333	8.229	0.000*
Display by Trial	1.088	2	0.544	0.437	0.647
Ability by Display by Trial	0.105	2	0.053	0.042	0.959
Error	1116.491	72	15.507		

alpha = .01

* = significant at the .01 level

significantly from trial to trial, $F(2, 72) = 10.243$, $p = .000$. Data did not reveal a significant performance difference between display types. There was, however, a significant interaction between spatial ability and trial, $F(2, 72) = 8.229$, $p = .000$.

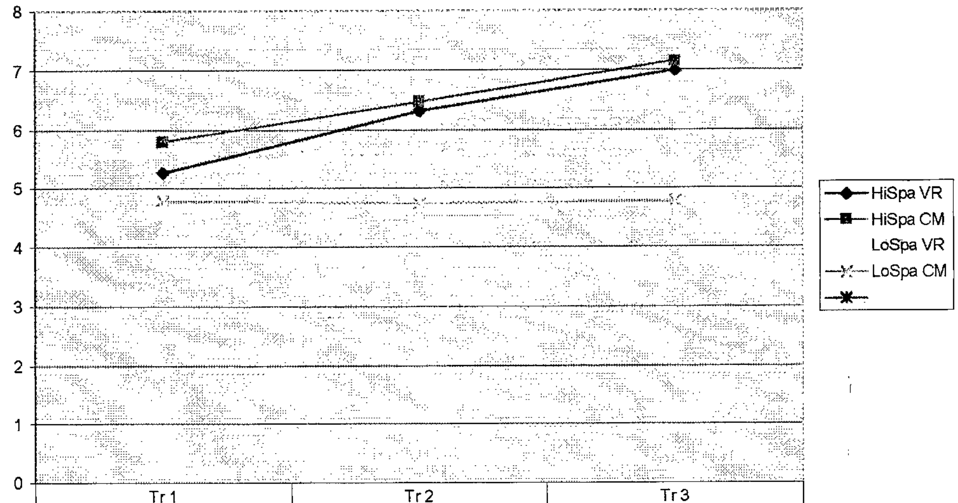
Figure 4 illustrates the number of ships destroyed per trial as a factor of spatial ability and display type. The rising slope for high spatial ability subjects shows an increase in performance regardless of display platform. The flat line for low spatial ability subjects suggests that their performance did not increase over time regardless of display type.

The performance of subjects in the two spatial ability groups was analyzed separately to determine the effects of display type and trial on number of ships destroyed by high and low spatial ability subjects. Table 3 provides an ANOVA summary table for the performance of the high spatial ability group. ANOVA indicated that performance of the higher spatial ability subjects increased significantly between trials (Trial 1 $M = 5.5$, SD $= 2.1$, Trail 2 $M = 6.4$, SD $= 2.2$, Trial 3 $M = 7.1$, SD $= 2.5$), $F(2, 36) = 19.771$, $p = .000$. A separate ANOVA for performance of lower spatial ability subjects (Trial 1 $M = 4.5$, SD $= 2.9$, Trial 2 $M = 4.6$, SD $= 2.6$, Trail 3 $M = 4.6$, SD $= 1.9$) did not reveal any significant differences by trial, indicating no performance gain after practice, $F(2, 36) = 0.06$, $p = .94$. ANOVA did not reveal any significant differences by display or any interaction effects between display type and trial for either spatial ability group.

Performance for each trial was also analyzed separately to determine the effects of spatial ability and display type over each individual trial. ANOVA for Trial 1 did not reveal any significant performance differences for spatial ability or display type

Figure 4.

Number of Enemy Ships Destroyed per Trial by Spatial Ability and Display Type



	Tr 1	Tr 2	Tr 3
HiSpa VR	5.263	6.316	7
HiSpa CM	5.789	6.474	7.158
LoSpa VR	4.316	4.526	4.474
LoSpa CM	4.789	4.737	4.789

Table 3

ANOVA Summary Table for Performance of High Spatial Ability Group

Source	SS	DF	MS	F-RATIO	P
Display Type	2.246	1	2.246	0.158	0.694
Trial	46.018	2	23.009	19.771	0.000*
Display by Trial	0.860	2	0.430	0.369	0.692
Error	512.421	36	14.234		

alpha = .01

* = significant at the .01 level

on the first trial. Table 4 provides an ANOVA summary table for performance on Trial 2. ANOVA indicated that high spatial ability subjects performed significantly better than low spatial ability subjects on the second trial (High $\underline{M}$ = 6.4, SD = 2.2, Low $\underline{M}$ = 4.6, $\underline{SD}$ = 2.6), $\underline{F}(1, 72) = 9.861$, $\underline{p} = 0.002$. Table 5 provides an ANOVA summary table for Trial 3 performance. ANOVA also indicated that high spatial ability subjects performed significantly better than low spatial ability subjects on the third trial (High $\underline{M}$ = 7.1, $\underline{SD}$ = 2.5, Low $\underline{M}$ = 4.6, $\underline{SD}$ = 1.9), $\underline{F}(1, 72) = 21.653$, $\underline{p} = 0.000$. ANOVA did not reveal any significant differences by display or any interaction effects between display type and spatial ability for any trial.

Performance Strategy

Table 6 shows the distribution of performance strategies by spatial ability and display type. The data shows that 24 high spatial ability subjects and 13 low spatial ability subjects used Strategy 1 (Slow Circling), 12 high spatial ability subjects and 19 low spatial ability subjects used Strategy 2 (Rapid Circling), and two high spatial ability subjects and six low spatial ability subjects used Strategy 3 (Straight-line Flight). Overall, 37 subjects used Strategy 1, 31 subjects used Strategy 2, and eight subjects used Strategy 3.

Effect of strategy use on performance. Means and standard deviations for performance as a factor of strategy used are reported in Table 7. These data revealed that the average number of ships destroyed per trial was 7.7 ($\underline{SD}$ = 2.3) for subjects using Strategy 1 (Slow Circling), 4.5 ($\underline{SD}$ = 1.2) for subjects using Strategy 2 (Rapid Circling) and 3.0 ($\underline{SD}$ =1.0) for subjects using Strategy 3 (Straight-line Flight).

Table 4

ANOVA Summary Table for Trial 2 Performance Scores

Source	SS	DF	MS	F-RATIO	P
Spatial Ability	59.066	1	59.066	9.861	0.002*
Display Type	0.645	1	0.645	0.108	0.744
Ability by Display	0.013	1	0.013	0.002	0.963
Error	431.263	72	5.990		

alpha = .01

* = significant at the .01 level

Table 5

ANOVA Summary Table for Trial 3 Performance Scores

Source	SS	DF	MS	F-RATIO	P
Spatial Ability	113.803	1	113.803	21.653	0.000*
Display Type	1.066	1	1.066	0.203	0.654
Ability by Display	0.118	1	0.118	0.023	0.881
Error	378.421	72	5.256		

alpha = .01

* = significant at the .01 level

Table 6

Frequency Distribution of Performance Strategy by Spatial Ability and Display Type

	Strat. One		Strat. Two		Strat. Three	
	HMD	Monitor	HMD	Monitor	HMD	Monitor
Hi Spa.	13	11	5	7	1	1
Lo Spa.	6	7	11	8	2	4
Total	19	18	16	15	3	5
Overall	37		31		8	

Table 7

Number of Enemy Ships Destroyed as a Factor of Strategy

	Trial One		Trial Two		Trial Three		
	HMD	Monitor	HMD	Monitor	HMD	Monitor	Total
Strat. 1	6.1	8.1	7.0	7.4	7.4	7.9	7.7
SD	2.5	3.5	2.7	2.6	2.2	2.3	2.3
Strat. 2	4.7	4.4	4.0	4.8	4.3	4.5	4.5
SD	1.7	1.1	1.2	1.5	1.4	1.2	1.2
Strat. 3	2.0	2.9	3.0	3.2	2.7	3.2	3.0
SD	0.7	0.4	1.0	0.8	1.5	0.8	1.0
Total	4.8	5.3	5.4	5.6	5.7	6.0	5.4
SD	2.2	2.8	2.6	2.5	2.5	2.6	2.4

Figure 5 illustrates that strategy use had an impact on performance regardless of trial.

Table 8 provides a summary of a stepwise multiple regression analysis for simulation performance. These data indicated that performance strategy use and spatial ability significantly increased the amount of performance variance explained (R squared). However, strategy use had the greatest effect on simulation performance. Strategy use accounted for 41% of performance variance, F (4, 71) = 129.153, p = .000. Spatial ability level accounted for a 1.6% increase in performance variance explained, F (4, 71) = 6.166, p = .01. With performance strategy out of the equation, spatial ability could only account for 13% of the variance explained, F (1, 74) = 11.227, p = .001. Display type and trial did not significantly increase the amount of performance variance explained.

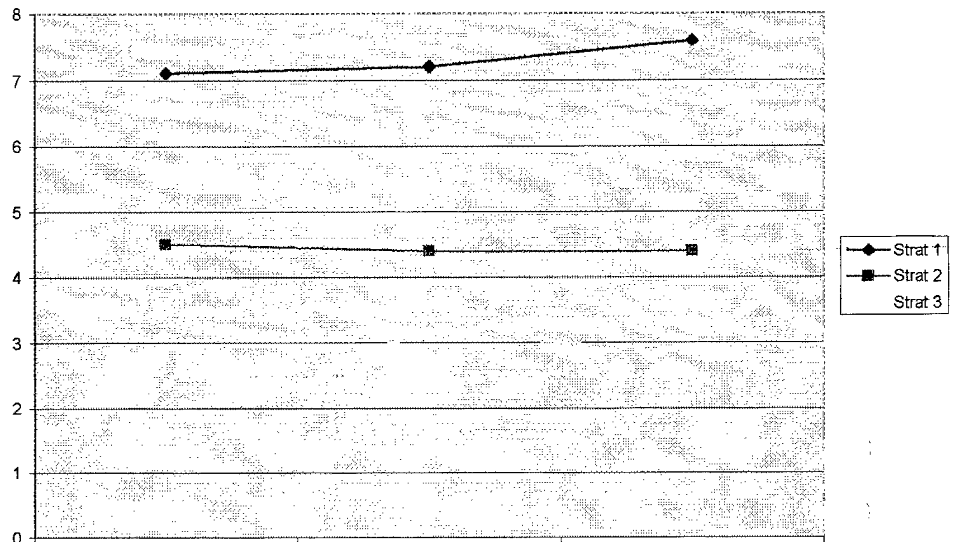
The correlation between performance and strategy use was found to be positive (r = .67) and statistically significant (p = .000) as was the correlation between spatial ability and performance (r= .36), (p = .001).

<u>Simulation discomfort</u>

Means and standard deviations for simulation discomfort (1 represents no symptoms and 4 represents severe symptoms) are included in Table 9. These data revealed a discomfort index of 1.32 (<u>SD</u> = 0.30) for high spatial ability subjects and 1.32 (<u>SD</u> = 0.28) for the low spatial ability subjects. Table 9 also shows a mean overall discomfort index of 1.34 (<u>SD</u> = 0.30) for the HMD and 1.29 (<u>SD</u> = 0.28) for the standard computer monitor. The overall discomfort levels per trial were 1.27 (<u>SD</u> = 0.26) for Trial 1, 1.30 (<u>SD</u> = 0.27) for Trial 2 and 1.38 (<u>SD</u> =0.34) for Trial 3.

Figure 5.

Number of Enemy Ships Destroyed as a Factor of Performance Strategy



	Trial 1	Trial 2	Trial 3
Strat 1	7.1	7.2	7.6
Strat 2	4.5	4.4	4.4
Strat 3	2.4	3.1	2.9

Table 8

Summary of Multiple Regression Analysis for Performance Scores

Variable	R Sqd.	R Sqd. Increase	F	p
Strategy	.412	.412	129.153	.000*
Spatial Ability	.428	.016	6.166	.014*
Display Type	.439	.011	4.481	.035
Trial	.439	.000	1.126	.290

df = 4, 71

alpha = .01

* = significant at the .01 level

Table 9

Simulation Discomfort Index per Spatial Ability, Trial, and Display Type

	Trial One		Trial Two		Trial Three		
	HMD	Monitor	HMD	Monitor	HMD	Monitor	Total
Hi Spa.	1.37	1.23	1.35	1.24	1.44	1.27	1.32
SD	0.32	0.23	0.29	0.27	0.40	0.28	0.30
Lo Spa.	1.25	1.23	1.29	1.33	1.37	1.46	1.32
SD	0.25	0.25	0.25	0.27	0.31	0.39	0.28
Total	1.31	1.23	1.32	1.28	1.40	1.37	1.32
SD	0.28	0.24	0.27	0.27	0.35	0.33	0.29

Overall Means

Hi Spatial = 1.32	HMD = 1.34	Trial One = 1.27
Lo Spatial = 1.32	Monitor = 1.29	Trial Two = 1.30
		Trial Three = 1.38

Figure 6 shows simulation discomfort response levels by display type. A blue line represents subjects wearing the HMD (Tr. 1 M = 1.31, Tr. 2 M = 1.32, Tr. 3 M = 1.41) and a red line represents subjects on a standard computer monitor (Tr. 1 M = 1.23, Tr. 2 M = 1.28, Tr. 3 M =1.37). Figure 6 shows an overall higher level of discomfort for the HMD group over the monitor group. The figure also shows slight increases in discomfort from trial to trial regardless of display type.

Table 10 shows that there was some general discomfort during the simulation (M = 1.49, SD = 0.64) with the highest discomfort rating being generated by the question relating to eye strain (M = 1.80, SD = 0.72). After eye strain, difficulty focusing was the next highest rated discomfort (M = 1.46, SD = 0.69). However, most subjects reported low levels of boredom (M = 1.18, SD = 0.45).

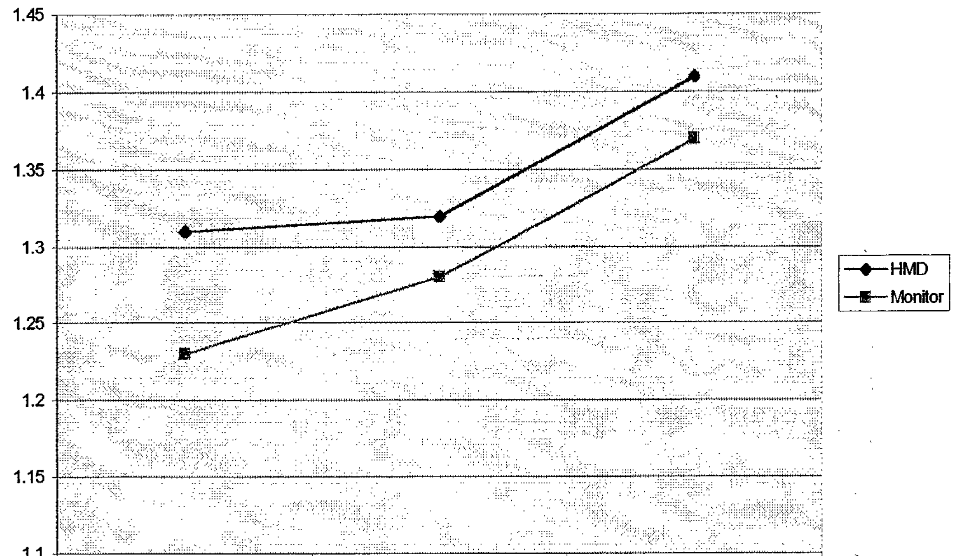
All twelve simulation discomfort survey items were analyzed individually using ANOVA. Only two items showed statistically significant differences. On questions 7 (Difficulty focusing) and 10 (Cold Sweating) there were significantly higher levels of discomfort for subjects using the HMD over subjects using the computer monitor (Q7, $F(1, 216) = 5.675$, $p = 0.01$; Q10, $F(1, 216) = 7.737$, $p = 0.006$).

Display characteristics

Means and standard deviations for the display characteristics survey are reported in Table 11. The numbers represent Likert-scale responses ranging from 1 (very acceptable) to 4 (very unacceptable) on items relating to display type characteristics. The data indicated that subjects found the resolution to be acceptable (M = 1.76, SD = 0.417). Display brightness (M = 1.47, SD = 0.506), color uniformity (M = 1.48, SD = 0.575), color uniformity (M = 1.48, SD = 0.575), and color vividness (M = 1.47, SD = 0.527)

Figure 6.

Simulation Discomfort Responses per Trial and Display Type



	Tr 1	Tr 2	Tr 3
HMD	1.31	1.32	1.41
Monitor	1.23	1.28	1.37

Table 10

Overall Simulation Discomfort Survey Responses by Spatial Ability and Display Type

Discomfort Survey Item	HMD High	HMD Low	Monitor High	Monitor Low	Total
1. General discomfort	1.61	1.45	1.37	1.52	1.49
2. Fatigue	1.44	1.30	1.28	1.40	1.35
3. Boredom	1.18	1.07	1.26	1.22	1.18
4. Drowsiness	1.30	1.28	1.21	1.22	1.25
5. Headache	1.30	1.17	1.28	1.17	1.23
6. Eye strain	1.95	1.80	1.70	1.75	1.80
7. Difficulty focusing	1.49	1.65	1.17	1.52	1.46
8. Dry mouth	1.01	1.10	1.21	1.28	1.17
9. Excess salivation	1.17	1.02	1.19	1.21	1.14
10. Cold sweating	1.47	1.10	1.02	1.19	1.19
11. Nausea	1.30	1.17	1.10	1.17	1.18
12. Blurred vision	1.40	1.54	1.21	1.45	1.40
Total	1.38	1.30	1.26	1.34	1.32

Note. Responses ranged from 1 (no symptoms) to 4 (severe symptoms).

Table 11

Display Characteristics Survey Responses by Display Type

Display Characteristics Survey Item		Display Type HMD	Monitor	Total
1.	Display resolution (absence of blur, ability to see fine detail)	1.98	1.55	1.76
2.	Display brightness	1.47	1.47	1.47
3.	Object-to-background contrast in visual scene	1.73	1.53	1.63
4.	Uniformity of color	1.55	1.42	1.48
5.	Color vividness (absence of washout)	1.52	1.42	1.47
6.	Depth cues from visual scene	2.03	1.94	1.98
7.	Motion cues from visual scene	1.63	1.79	1.71
8.	Image distortion	1.76	1.68	1.72
9.	Display noise (visible artifacts that are not part of the original scene)	1.68	1.60	1.64
10.	Display ghosting (double images)	1.55	1.45	1.50
Total		1.69	1.58	1.63

Note. Responses ranged from 1 (very acceptable) to 4 (very unacceptable).

were also rated as acceptable. The least acceptable item related to depth perception of visual scenes (M = 1.98, SD = 0.663).

All ten survey items were analyzed individually using ANOVA. This analysis indicated a significant difference in only one of the ten survey items. Subjects using the HMD rated display resolution significantly lower on item 1 than subjects using the computer monitor, $F(1, 74) = 15.388$, $p = 0.000$.

Attitude

Means and standard deviations for the attitude survey are reported in Table 12. The numbers represent a scale from 1 (strongly agree) to 4 (strongly disagree).
Data indicated that the subjects generally enjoyed the simulation (M = 1.31, SD = 0.524) and tried hard to perform well (M= 1.23, SD = 0.429). There was a higher level of disagreement reported on items relating to receiving sufficient practice prior to the simulation (M= 1.77, SD = 0.774) and whether the skills required for the simulation were appropriate for potential Air Force pilots (M= 1.81, SD = 0.769). Subjects also responded somewhat negatively to the item about feeling a part of the simulation (M = 1.85, SD = 0.747).

All ten attitude survey items were analyzed individually using ANOVA. This analysis did not result in any significant differences on any item by spatial ability or display type.

Table 12

Attitude Survey Responses by Display Type and Spatial Ability

Attitude Survey Item	Display type HMD High	HMD Low	Monitor High	Monitor Low	Total
1. There was enough practice before the simulation	1.68	2.0	1.74	1.68	1.77
2. I thought the simulation challenged my skills	1.58	1.52	1.52	1.63	1.57
3. I was comfortable during the simulation	1.47	1.84	1.63	1.58	1.63
4. I really felt I was a part of the simulation	1.95	1.74	1.95	1.79	1.85
5. I tried hard to perform well in the VR space duel	1.21	1.31	1.26	1.15	1.23
6. I enjoyed the space duel	1.26	1.31	1.37	1.31	1.31
7. The simulation was about the right length	1.74	1.68	1.47	1.68	1.64
8. The skills required in the space duel are appropriate for potential Air Force pilots.	1.84	2.05	1.79	1.58	1.81
9. I wish we practiced these types of skills more often	1.47	1.52	1.68	1.52	1.55
10. I would like to use other programs similar to this one	1.26	1.26	1.42	1.42	1.34
Total	1.55	1.62	1.58	1.53	1.57

Note. Responses ranged from 1 (strongly agree) to 4 (strongly disagree).

CHAPTER IV

DISCUSSION

The purpose of this study was to investigate the effects of display type (Head-Mounted Display vs. computer monitor) and spatial ability (high vs. low) on performance during three trials of a virtual reality simulation. The study examined the effects of display type, spatial ability, and number of trials on simulation performance, strategy use, discomfort level, display characteristics, and attitude.

Results for performance indicated that subjects with high spatial ability performed significantly better on the simulation than subjects with low spatial ability. Furthermore, performance results revealed a significant interaction between spatial ability and trial. Separate analyses for each spatial ability group showed that the performance of high spatial ability subjects improved significantly from trial to trial. In contrast, the performance of low spatial ability subjects did not significantly improve over time.

It is not surprising that high spatial ability subjects performed better than low spatial ability subjects in this study. It was expected that subjects who were better capable of mentally visualizing an object's rotation on the test of spatial ability would perform better on a task that required them to actually "rotate" objects suspended in a

virtual space. Other researchers have demonstrated that performance on spatial tasks is related to scores on standard measures of spatial ability (Gopher & Weil, 1989, Subrahmanyam & Greenfield, 1994).

The finding that spatial ability and trial interacted to influence performance in the current study was somewhat surprising. High spatial ability subjects' performance improved significantly from trial to trial, while low spatial ability subjects' performance did not significantly improve over time. In fact, low spatial ability subjects showed almost no practice effects after three trials and 45 minutes of exposure to the spatial task. This result does not support other researchers who have reported that low spatial ability subjects can benefit more from practice than high spatial ability subjects (Gopher & Weil, 1989, Hays, 1996, Subrahmanyam & Greenfield, 1994).

A possible explanation for the lack of practice effects for low spatial ability subjects resides in the simulation implemented in this study. The Space Duel simulation required a high degree of concentration and good hand-to-eye coordination. Other studies have used commercially available "gaming" software of a less challenging nature. Furthermore, low spatial ability subjects may not have been able to process the large amount of visual information in the Space Duel simulation. At any given time, they were required to monitor velocity, altitude, aircraft attitude relative to the horizon, thrust, and energy levels. It is possible that many became overwhelmed by the task.

It is also possible that the treatment was not long enough to affect low spatial ability subjects. Studies that have found practice effects for low spatial subjects have

implemented treatments ranging from 2.5 hours (Subrahmanyam & Greenfield, 1994) to ten hours (Fabiani et al., 1989, Foss et al., 1989). Subjects in the current study were exposed to three, fifteen-minute trials for a total of 45 minutes of exposure. It is possible that low spatial ability subjects did not have enough time in the simulation for practice to have an effect on their performance.

While results did not show a practice effect for low spatial ability subjects, the performance of high spatial ability subjects did improve across trials. This may be due in part to the strategies used by high spatial subjects during the simulation. A majority of high spatial ability subjects in this study used strategies that have related to successful performance in other studies (Fabiani et al., 1989, Foss et al., 1989, Shapiro & Raymond, 1989).

Exploratory data analysis suggested that strategy use in this study was a better predictor of performance than spatial ability. Strategy use accounted for 41% of the variance in performance scores while spatial ability alone accounted for 13% of the variance.

There are several potential explanations why strategy use was a better predictor of performance than spatial ability. Strategy use had to do with how a subject adjusted to the demands of the simulation and the psychomotor responses he made in order to complete the task. It likely related to experience in simulations and games in general, for comfort and skill with a joystick, and other experiential factors that cannot be accounted for solely by a pencil and paper measure of spatial ability.

The spatial ability pretest, while effective in measuring general spatial ability, was not effective at accounting for prior gaming and psychomotor skills. In fact, two of

the three highest performers overall came from the low spatial ability group. These three subjects used a slow circling strategy during the simulation. Informal post-experiment interviews suggested that the common denominator for these three individuals was extensive prior experience with PC-based flight simulation games. On the other hand, the highest scorer on the spatial ability pretest was one of the poorest performers in the actual simulation. This subject reported never having used any flight simulation software and used straight-line flight as his performance strategy.

Several researchers have investigated the effects of experience and other factors on performance in complex spatial tasks. Okagaki and Frensch (1994) studied the effects of prior video gaming experience on performance of complex spatial tasks and found that subjects with extensive prior gaming experience performed significantly better than those with little to no experience. Rabbitt et al. (1989) found that an IQ measure was more effective at predicting success in a complex flight simulation game than a standard spatial ability measure. Studies by Raymond and Shapiro (1989) and Hays (1989) concentrated on training for successful performance strategies in order to affect the performance of lower ability subjects. In both cases, successful performance strategy instruction resulted in significant performance improvements by the subjects.

While findings indicated that strategy use and spatial ability related to performance in the current study, results did not indicate a significant performance difference between subjects using the head-mounted display (HMD) and those using the computer monitor. It was expected that the isolation effect of a helmet-mounted display would have some effect on performance since it should have provided subjects with a higher level of "immersion" than the computer monitor (Biocca & Delaney,

1995). Subjects may not have felt sufficiently immersed because of equipment specifications such as the size of the screens in the HMD. Furthermore, the effect of immersion may not have been enough to be detectable in the HMD over three trials with only 45 minutes of exposure.

Another explanation for the lack of performance effects for display type might be related to the subjects' perceptions of the HMD. Results indicated that subjects who used the HMD reported significantly more difficulty focusing than subjects that used the computer monitor. Furthermore, subjects using the HMD rated display resolution significantly lower than subjects using the computer monitor. Any increased level of immersion provided by the HMD may have been offset by its lower resolution and subjects' difficulty focusing.

In fact, it was predicted that subjects using the HMD would report more discomfort than they actually did. Other researchers have found that subjects using HMD's reported general discomfort (Kolasinski, 1995, Moshell et al., 1993, and Dede et al., 1997). In one study, this discomfort resulted in subjects not being able to complete the VR task (Dede et al., 1997). The lack of general discomfort in the current study may be explained by the HMD used by the subjects. The Virtual I/O headset was one of the lightest currently available and the liquid crystal displays (LCD's) were of high quality.

The explanation for resolution differences rests in the technical specifications of each display type. The helmet-mounted display consisted of dual 180,000 pixel miniature LCD screens while the computer monitor was a 14 inch, 400,000 pixel screen. It is technically impossible at the present time to build HMD's with much

greater resolutions because they then become unduly large and heavy. Consequently, HMD use will always incur a price in the form of lower resolutions. On the other hand, it was expected that the stereoscopic function of the HMD would significantly affect the perception of depth for the participants. Even though the helmet-mounted display was equipped with a stereoscopic system (dual offset screens for 3D imaging) subjects rated depth perception equally poorly on both displays. This leaves us with the requirement to develop ever lighter displays with truer resolution at an affordable cost.

Turning to attitude responses, there were no significant differences either by display type or spatial ability level. The program was equally engaging to those using the HMD and those using the computer monitor. Ironically, even though most enjoyed using the program and tried hard to perform well, there was not a clear feeling that the skills required to succeed in Space Duel would be appropriate to potential Air Force pilots.

This study has some implications for organizations such as the military that require proficiency on spatial tasks. From a resource utilization perspective, it can be argued that it is more economical and efficient to train individuals with high spatial ability rather than those with low spatial ability due to the shorter length of training time required. This could be especially true when costs of training units are very high such as is the case in military aviation. Yet while standard spatial ability measures do an acceptable job of predicting skill level in the general population, other measures such as strategy use might give us an even more accurate predictor of success in highly complex spatial skills. While spatial ability is related to the acquisition of complex

spatial tasks, organizations should consider using additional measures such as strategy use or prior experience when making selection decisions for training or employment. This might entail the addition of some type of psychomotor testing instrument to ensure a higher probability of selecting the most appropriate candidates for training.

This study also has implications for the use of VR systems for training on spatial tasks. The lack of significant differences between subjects using the two display types suggests that high resolution computer monitors are as effective as high cost HMD's. Furthermore, designers should exercise caution when selecting virtual platforms for the delivery of instruction. Careful analysis must be made of the required levels of visual fidelity with which the instruction can be delivered. Immersive virtual systems might induce a greater feeling of presence than standard displays, but their potential will not be realized if they provide poor fidelity or visual acuity. This is especially true for tasks that require identification of very small or detailed objects. In addition, a potential learner's comfort and perception of this kind of display type must be weighed when deciding what type of training platform to utilize.

There is still considerable research required before we can attempt to quantify the benefits and refine the potential of virtual reality systems. As Biocca et al. (1995) suggested earlier, "VR has yet to be proven and most systems still have the feel of prototypes. There is a lack of objective measures of performance. Research must be conducted on all aspects of virtual environment systems that have a possible bearing on participants performance" (pg. 13).

As VR technologies available to deliver instruction become more economically feasible, instructional designers and researchers should continue to explore variables

that can affect learning and performance in virtual environments. Only then can a complete picture of the viability of virtual reality systems as training platforms emerge.

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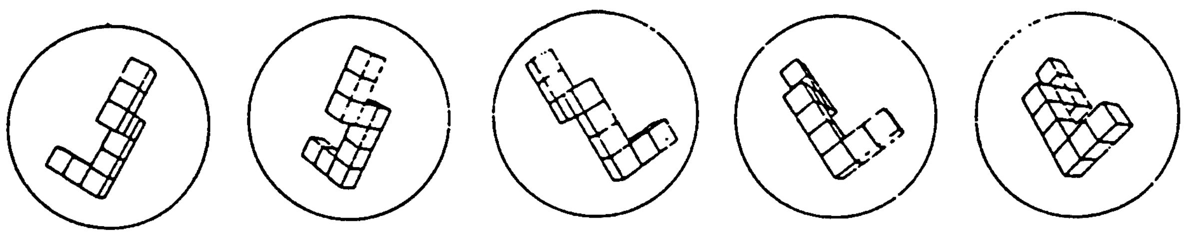
APPENDIX A

SPATIAL ABILITY PRETEST

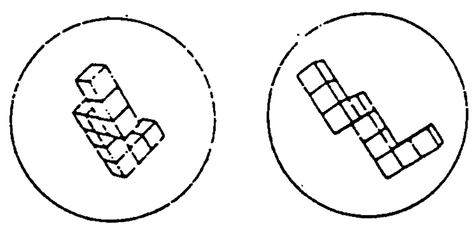
Name ______________________

M.R.T. Test Date ______________________

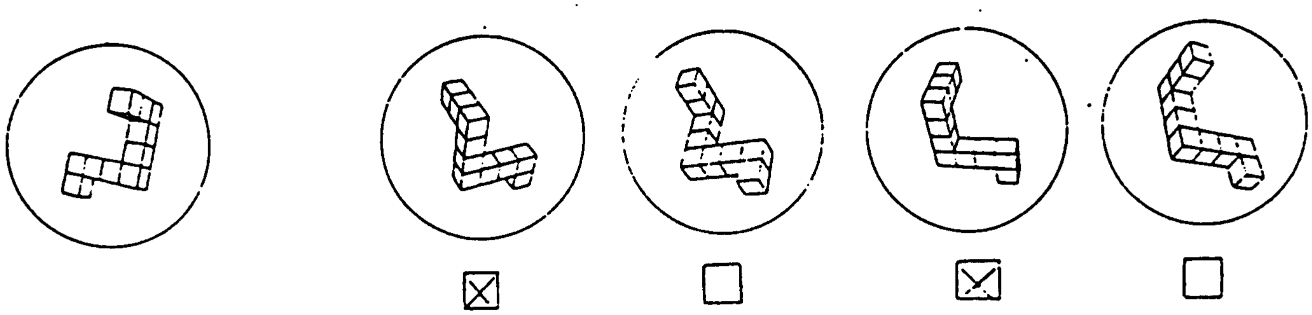
This is a test of your ability to look at a drawing of a given object and find the same object within a set of dissimilar objects. The only difference between the original object and the chosen object will be that they are presented at different angles. An illustration of this principle is given below, where the same single object is given in five different positions. Look at each of them to satisfy yourself that they are only presented at different angles from one another.



Below are two drawings of new objects. They cannot be made to match the above five drawings. Please note that you may not turn over the objects. Satisfy yourself that they are different from the above.



Now let's do some sample problems. For each problem there is a primary object on the far left. You are to determine which two of four objects to the right are the same object given on the far left. In each problem always <u>two</u> of the four drawings are the same object as the one on the left. You are to put Xs in the boxes below the correct ones, and leave the incorrect ones blank. The first sample problem is done for you.



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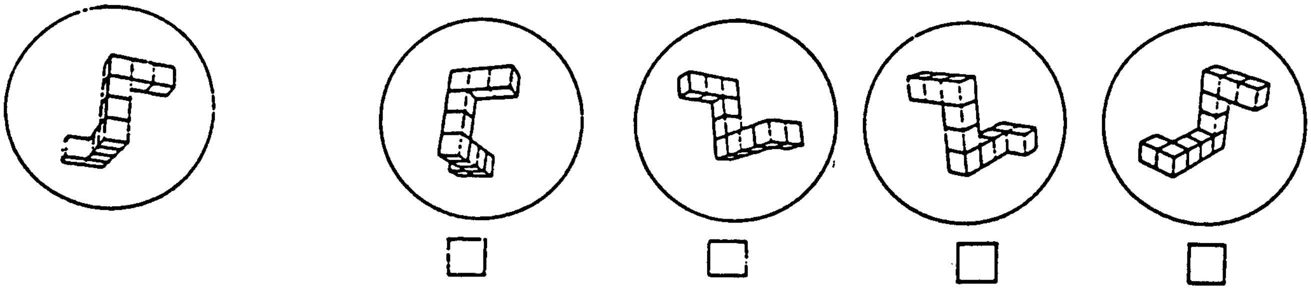
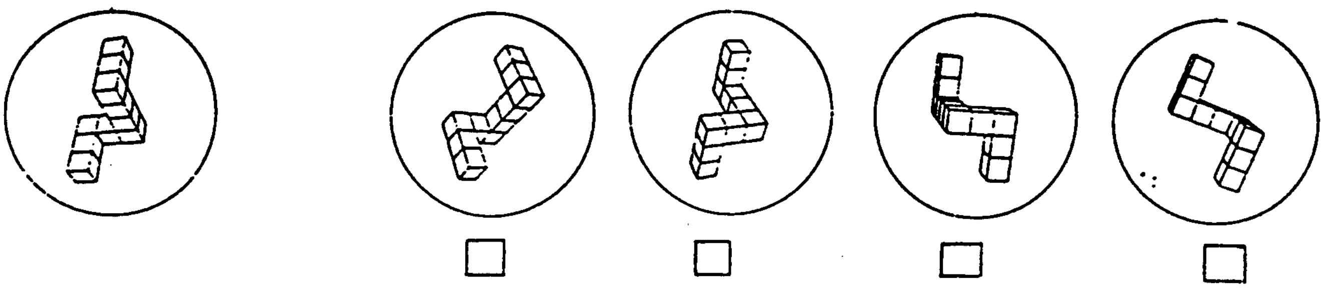
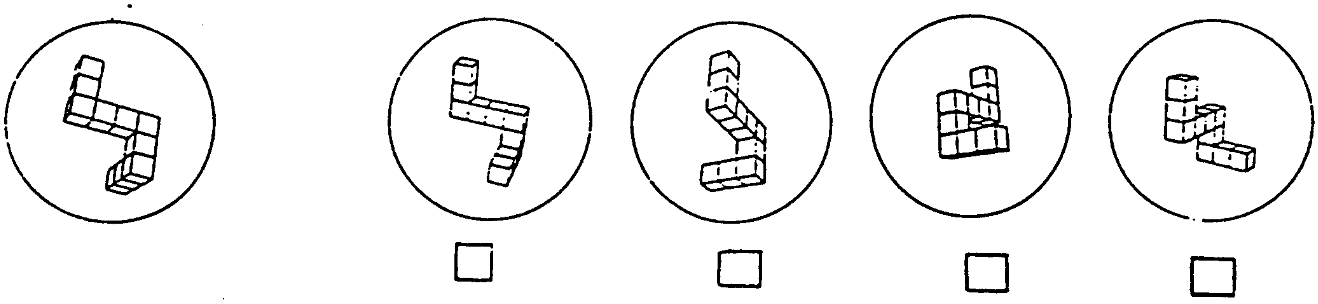
Adapted by S.G. Vandenberg, University of Colorado, July 15, 1971
Revised instructions by H. Crawford, U. of Wyoming, September, 1979

Do the rest of the sample problems yourself. Which two drawings on the right show the same object as the one on the left? There are always two and only two correct answers for each problem. Put an X under the two correct drawings.







Answers: (1) first and second drawings are correct
(2) first and third drawings are correct
(3) second and third drawings are correct

This test has two parts. You will have 3 minutes for each of the two parts. Each part has two pages. When you have finished Part I, STOP. Please do not go one to Part 2 until you are asked to do so. Remember: There are always two and only two correct answers for each item.

Work as quickly as you can without sacraficing accuracy. Your score on this test will reflect both the correct and incorrect responses. Therefore, it will not be to your advantage to guess unless you have some idea which choice is correct.

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PART I

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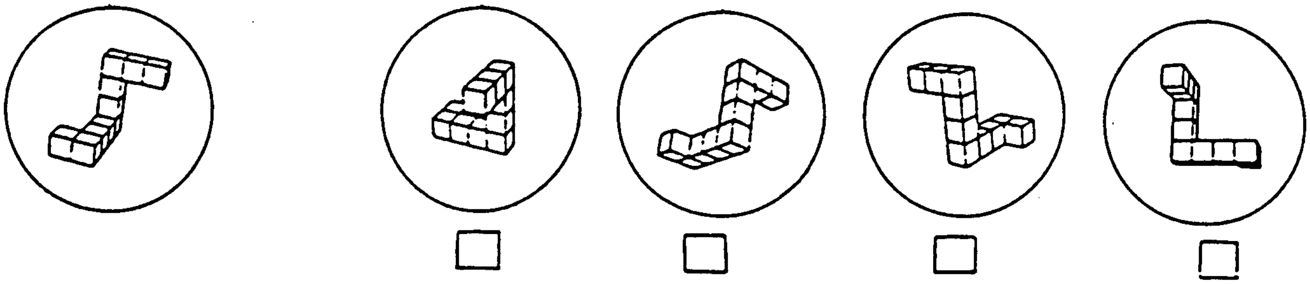

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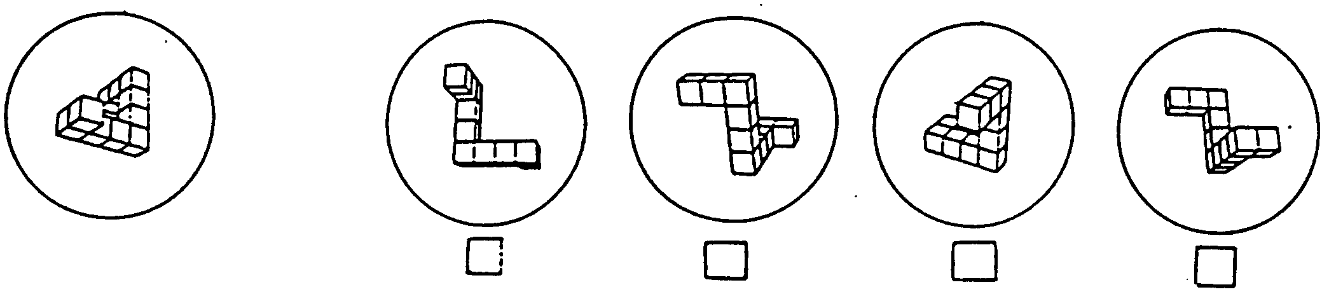

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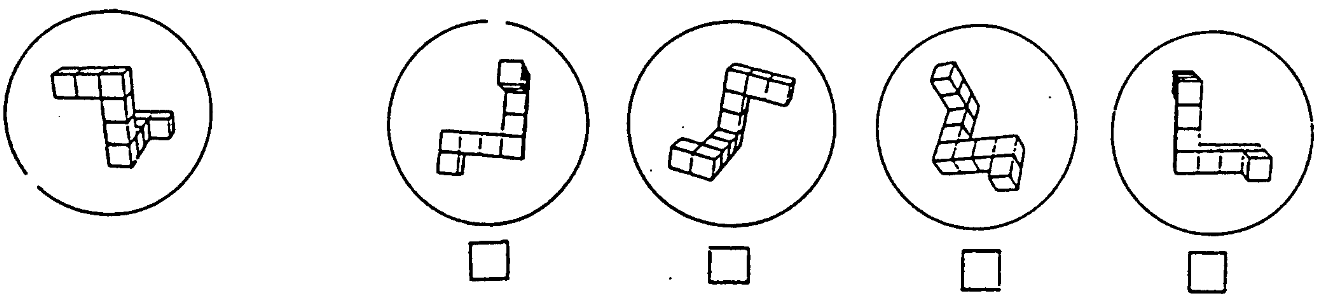

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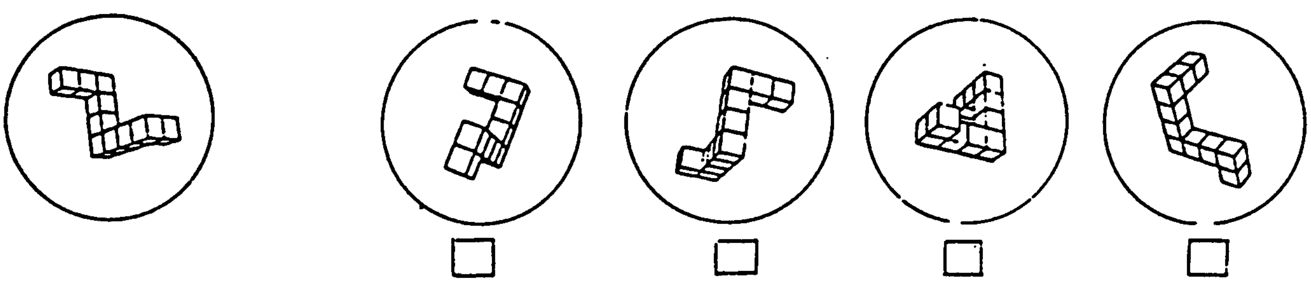

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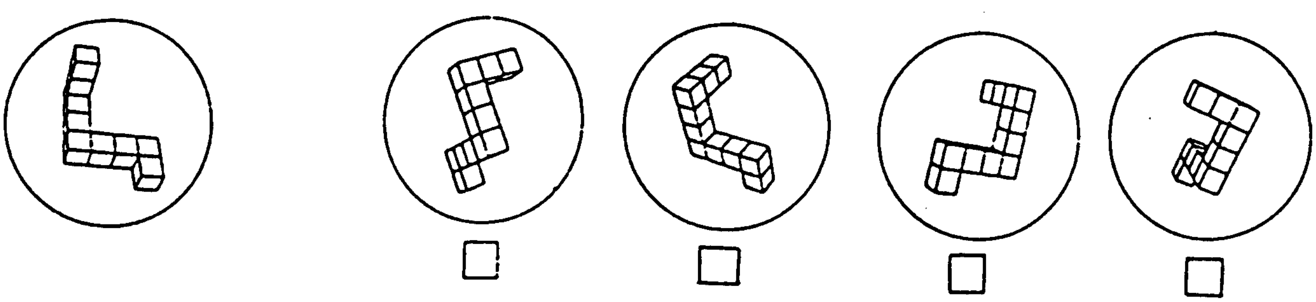

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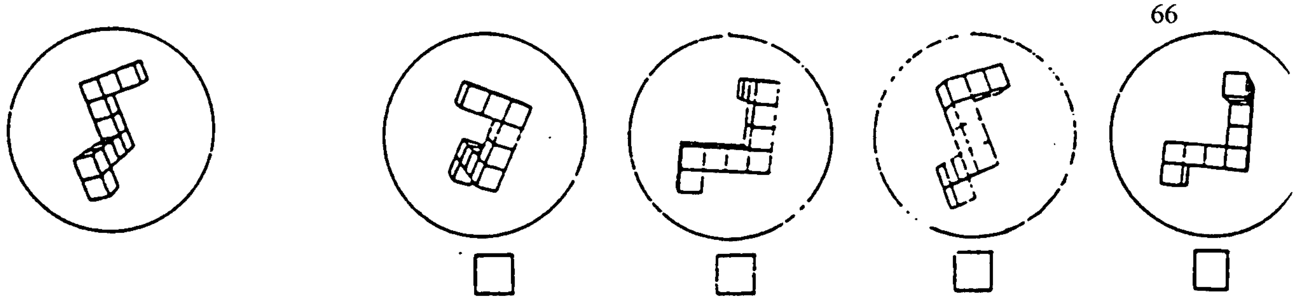
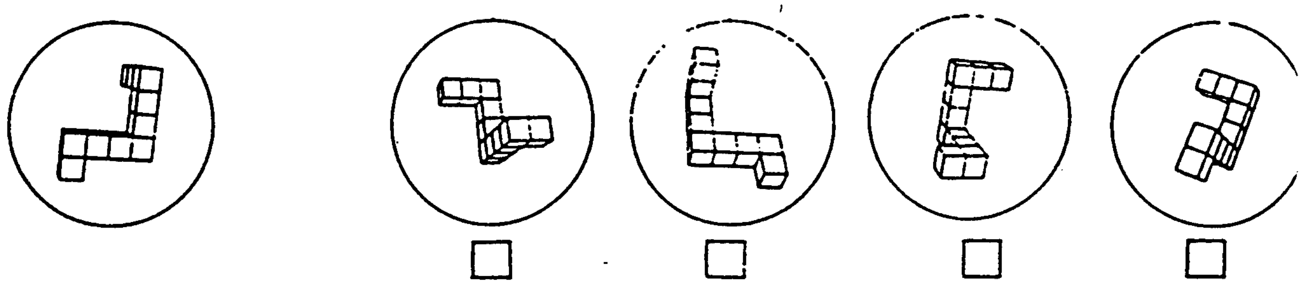
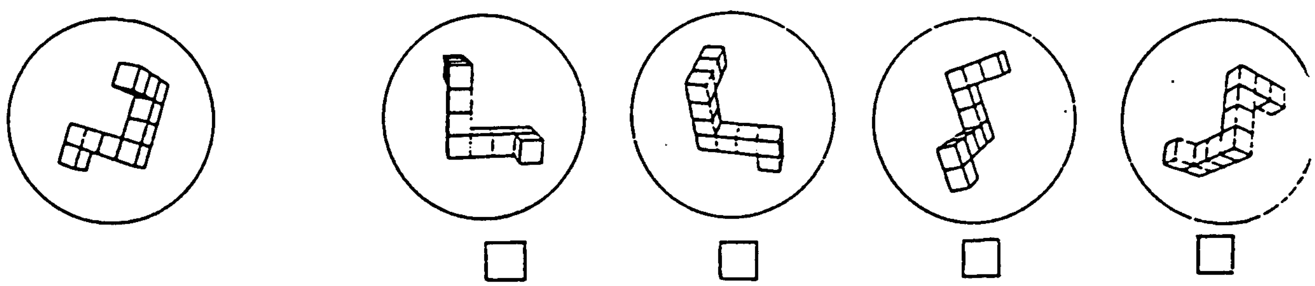
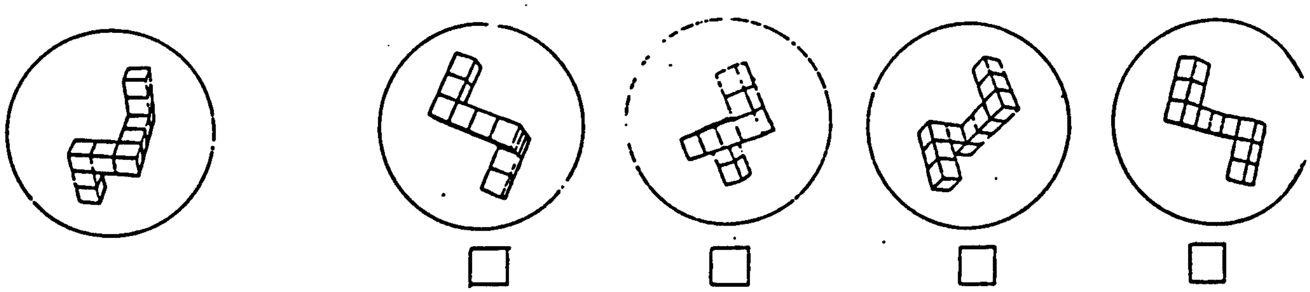
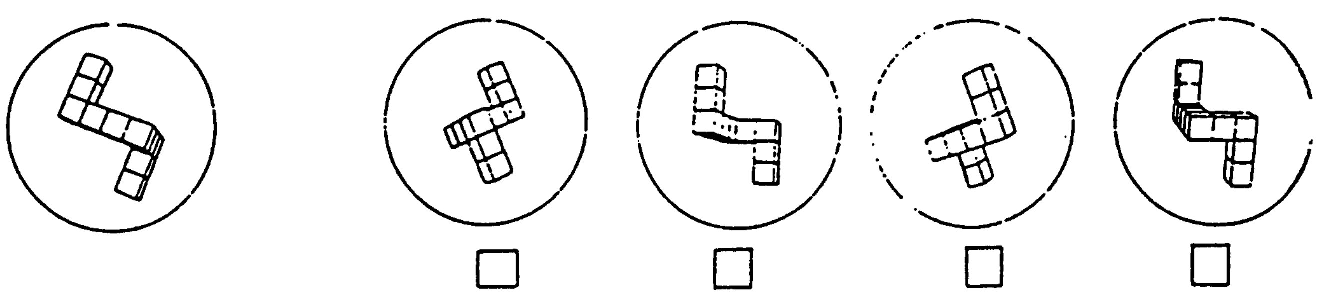
6. 

7. 

8. 

9. 

10. 

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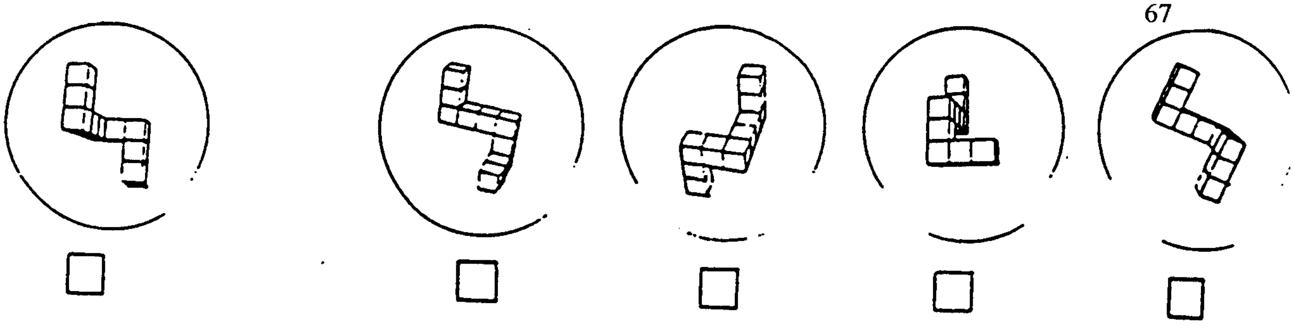
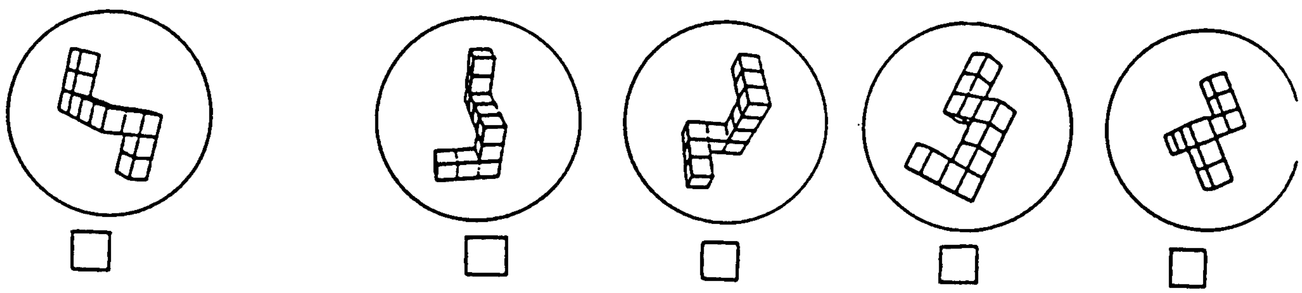
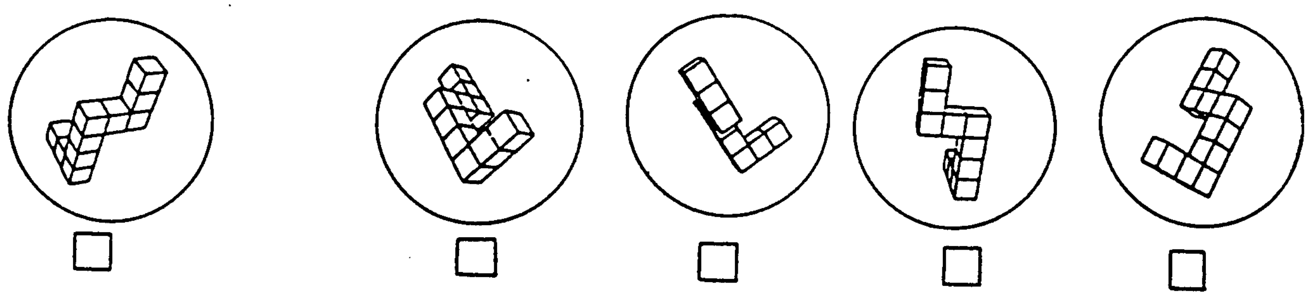
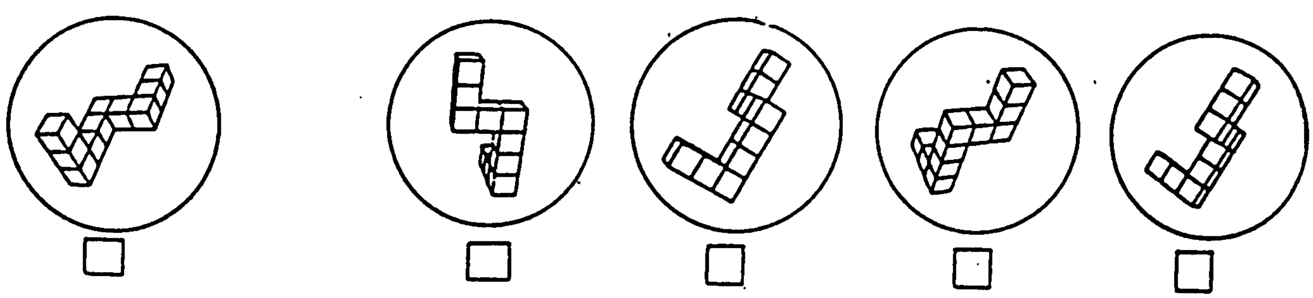
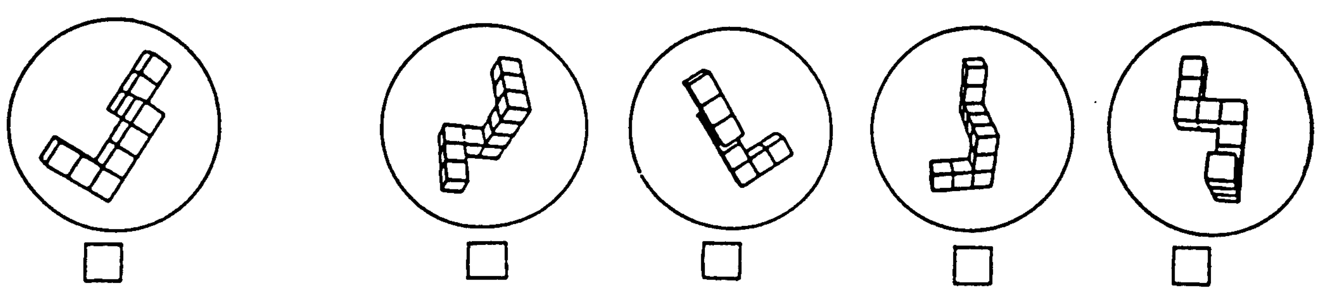
PART II

11. 

12. 

13. 

14. 

15. 

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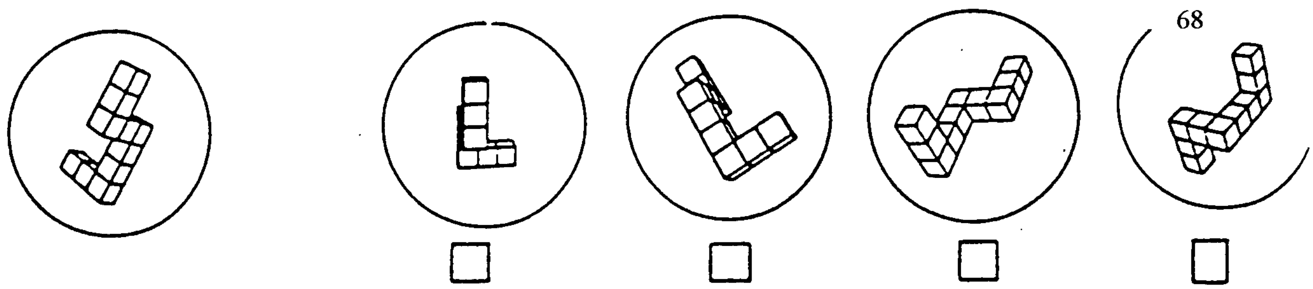
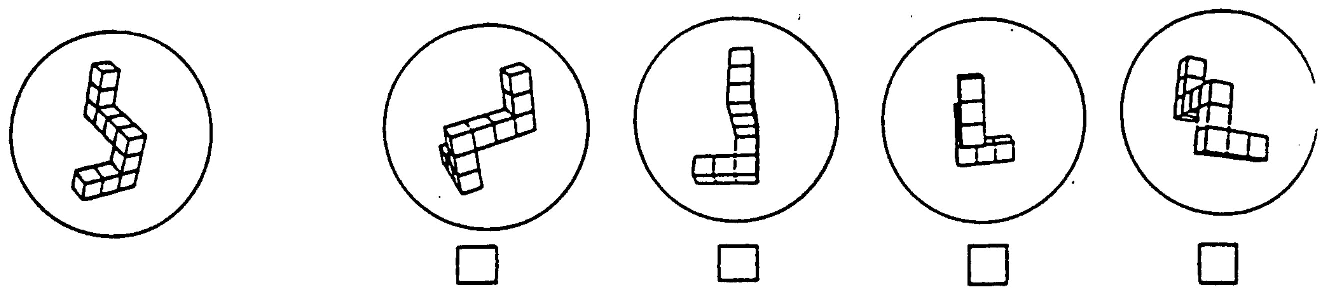
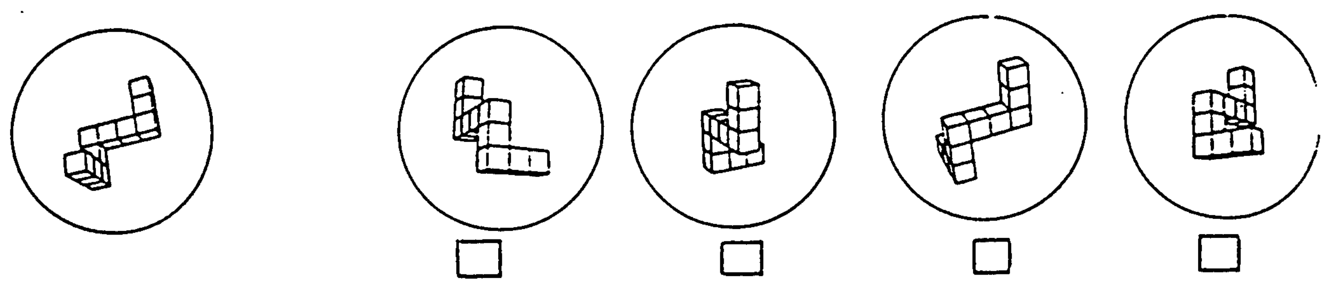
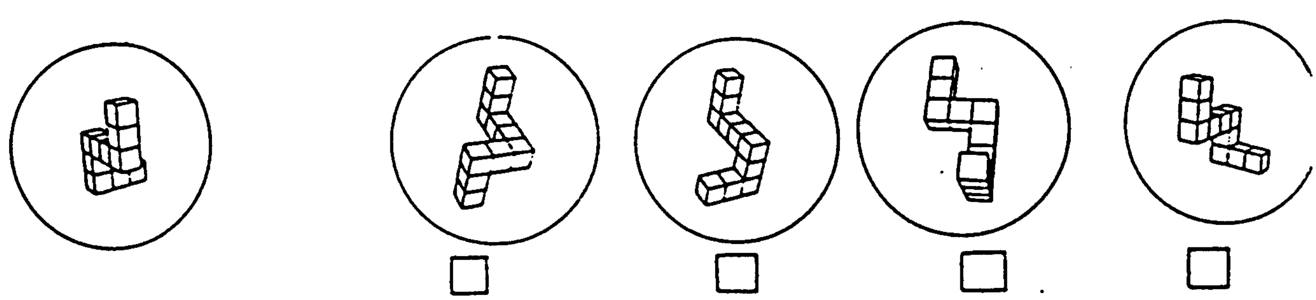
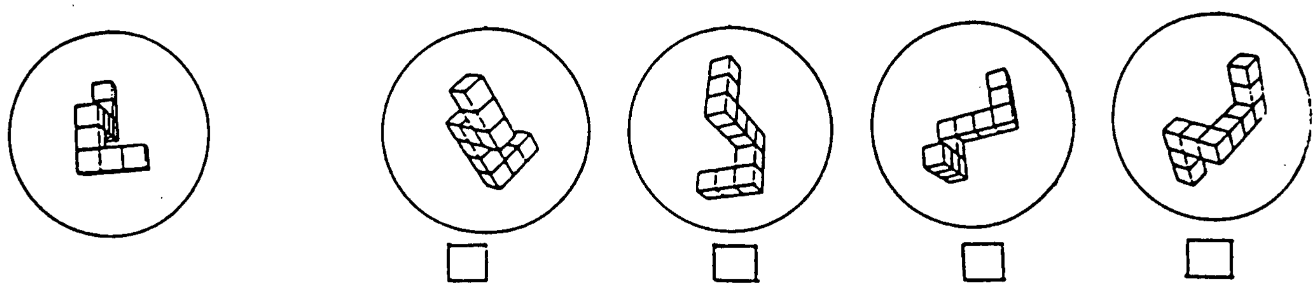
16. 

17. 

18. 

19. 

20. 

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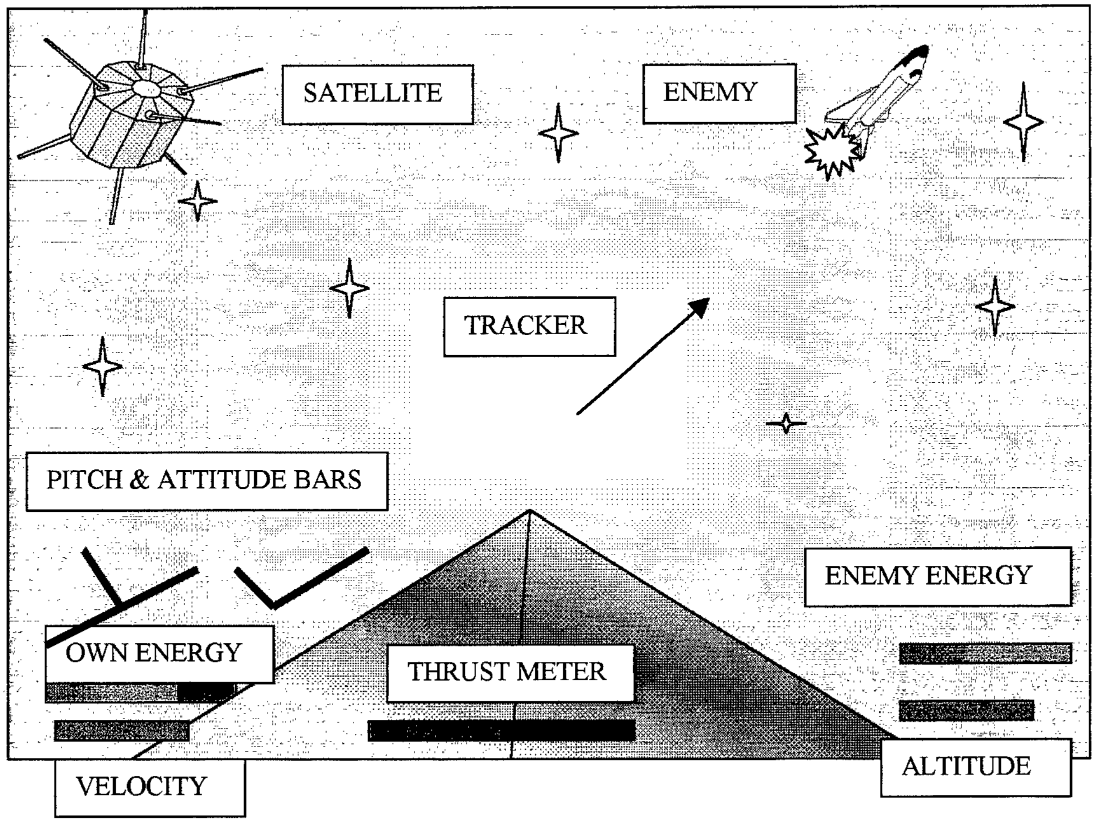
APPENDIX B

VR SPACE DUEL INSTRUCTIONS



VR Space Duel Instructions

Head-Mounted Display Treatment

Mission

Your mission in this simulation is to shoot and destroy an enemy spacecraft located in a deep space virtual environment. Shots are fired from a spaceship controlled by you using a joystick interface. In addition to destroying the enemy ship, you must attempt to conserve as much energy as possible. Both you and the enemy have a finite amount of available energy. To win, you must either destroy the enemy craft with guns or cause him to expend his energy before yours runs out.

Your ship is controlled and shots are fired by means of a joystick control interface manipulated by your right hand. The interface operates the trigger mechanism and the

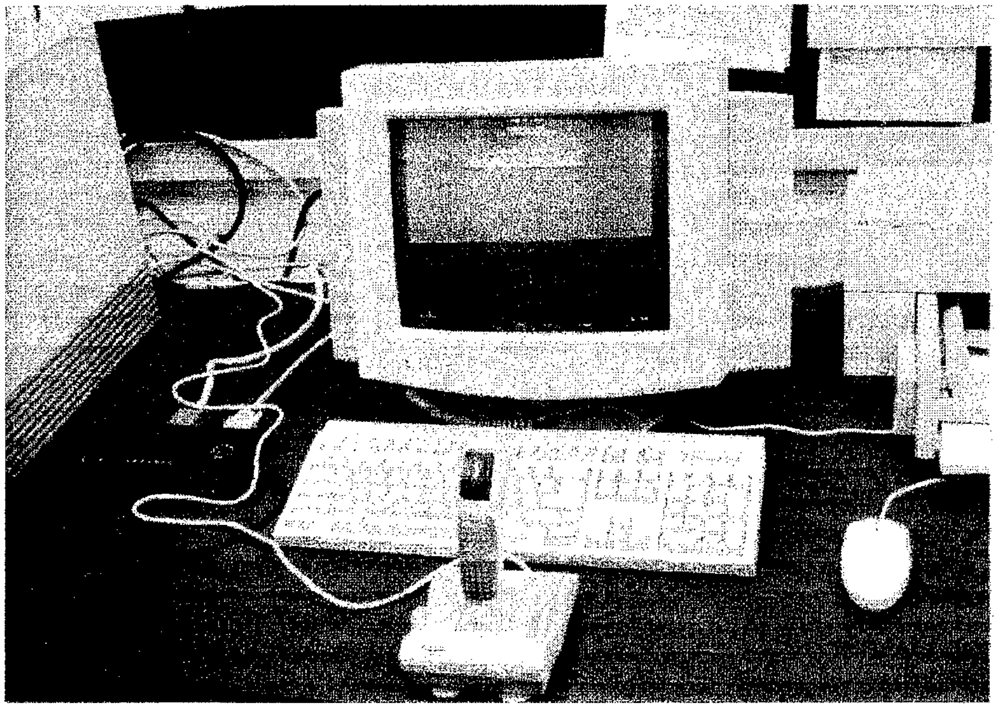
directional control of your ship. You can activate an enemy tracking device by pressing on the "T" letter key on the computer keyboard. You may also switch your outside viewing perspectives by pressing on the keyboard space bar.

In the course of destroying the enemy spacecraft, you must overcome a number of obstacles. First, the enemy will defend itself against your attacks. It does this by rotating to face your ship, and then trailing your ship's movements while firing shots at it. If you don't take evasive action, the enemy craft will run into your ship and damage it or simply destroy it with his guns. The enemy ship will also constantly maneuver to avoid your attacks, and may utilize existing physical obstacles to hide from your attacks.

Whenever the enemy spacecraft hits your ship, it will be damaged. When the ship is damaged for the third time, it will be destroyed and the simulation will restart. Your score is computed and displayed after each engagement. You can check your performance by looking at the status bar on the bottom part of the screen. Here you will find your and your opponents energy level as well as your ships altitude, acceleration, and attitude relative to the horizon.

View Manipulation

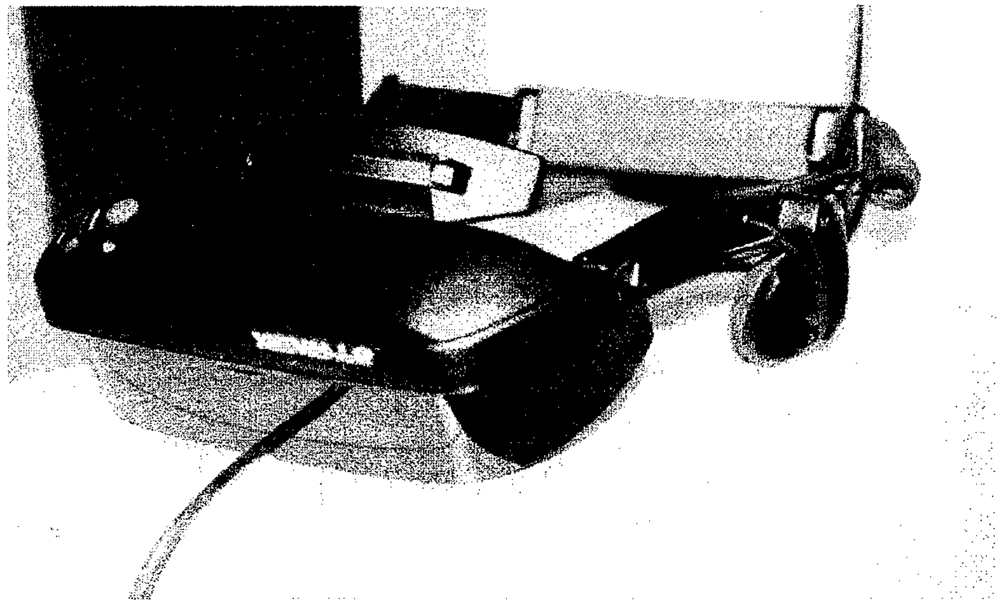
You can control your view perspective by using the space bar. There are three perspectives that can be selected. The first one will give you an internal cockpit view. The second perspective is an external chase view. The third perspective is a fixed external view. You may cycle through these by pressing on the keyboard space bar.



Computer with joystick interface

Joystick Interface

All control of your ship is accomplished using a joystick interface. To fire your guns, you must depress the "trigger" located in the top-front button of the control device. Aiming and directional control of your ship is accomplished by wrist movements transmitted by the joystick to the computer. To apply forward and backward thrust, you must use the mouse. Forward motion of the mouse applies forward thrust. Backward motion of the mouse applies backward thrust.



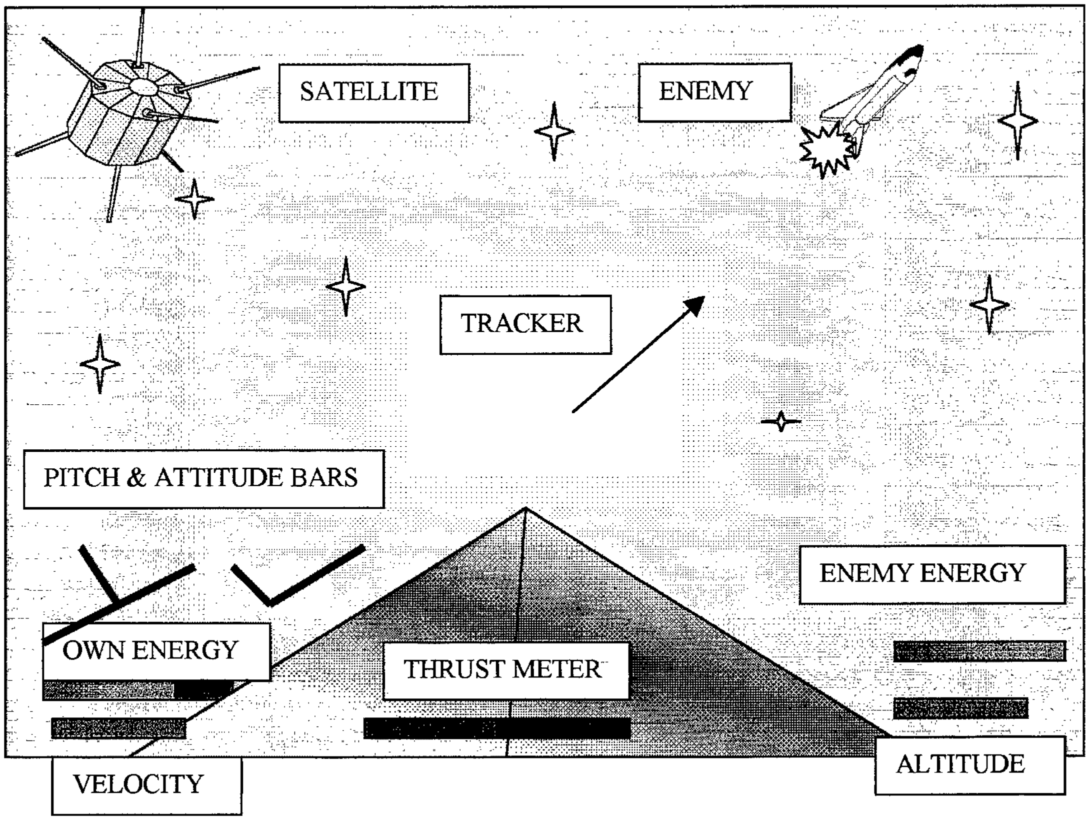
Virtual I/O Head-Mounted Display

Head-Mounted Display

You will be using a Virtual I/O Head-Mounted Display while accomplishing the simulation. An experimenter will assist you in donning the helmet and adjusting it for proper fit. If you wear glasses, it is recommended that you remove them for the simulation.

Familiarization period

Prior to beginning the actual simulation, the experimenter will allow you a five-minute familiarization trial period. Use this time to try out all the system functions, especially those related with ship control, aiming, and firing. After the five-minute familiarization period is over, you will begin the simulation. You will then have three fifteen-minute trials in which to fly the mission.



VR Space Duel Instructions

Computer Monitor Display Treatment

Mission

Your mission in this simulation is to shoot and destroy an enemy spacecraft located in a deep space virtual environment. Shots are fired from a spaceship controlled by you using a joystick interface. In addition to destroying the enemy ship, you must attempt to conserve as much energy as possible. Both you and the enemy have a finite amount of available energy. To win, you must either destroy the enemy craft with guns or cause him to expend his energy before yours runs out.

Your ship is controlled and shots are fired by means of a joystick control interface manipulated by your right hand. The interface operates the trigger mechanism and the

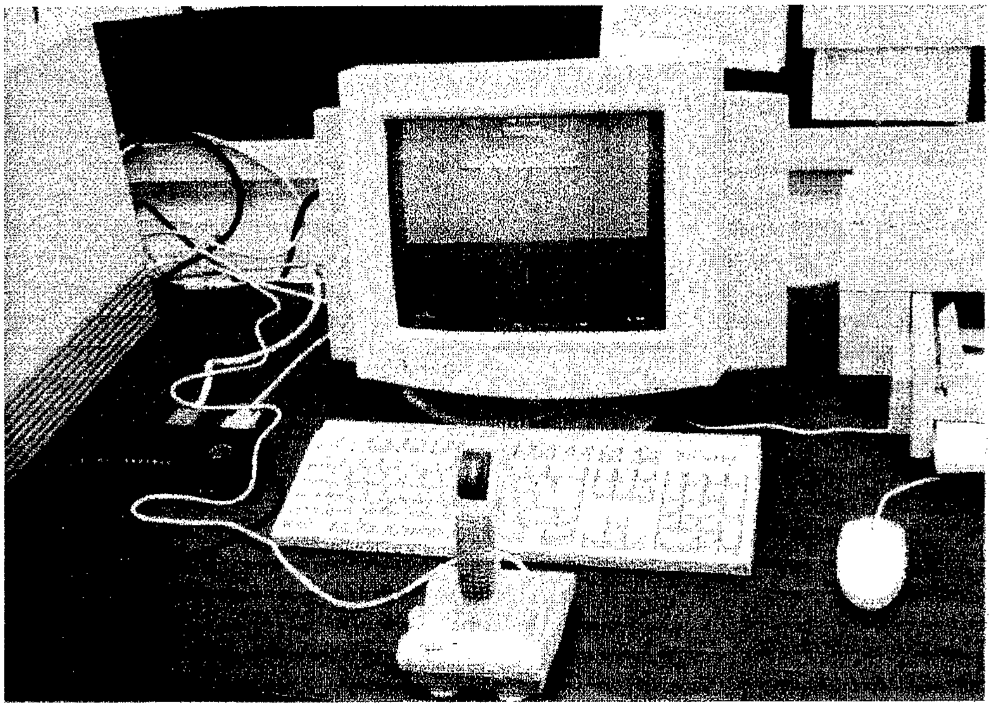
directional control of your ship. You can activate an enemy tracking device by pressing on the "T" letter key on the computer keyboard. You may also switch your outside viewing perspectives by pressing on the keyboard space bar.

In the course of destroying the enemy spacecraft, you must overcome a number of obstacles. First, the enemy will defend itself against your attacks. It does this by rotating to face your ship, and then trailing your ship's movements while firing shots at it. If you don't take evasive action, the enemy craft will run into your ship and damage it or simply destroy it with his guns. The enemy ship will also constantly maneuver to avoid your attacks, and may utilize existing physical obstacles to hide from your attacks.

Whenever the enemy spacecraft hits your ship, it will be damaged. When the ship is damaged for the third time, it will be destroyed and the simulation will restart. Your score is computed and displayed after each engagement. You can check your performance by looking at the status bar on the bottom part of the screen. Here you will find your and your opponents energy level as well as your ships altitude, acceleration, and attitude relative to the horizon.

View Manipulation

You can control your view perspective by using the space bar. There are three perspectives that can be selected. The first one will give you an internal cockpit view. The second perspective is an external chase view. The third perspective is a fixed external view. You may cycle through these by pressing on the keyboard space bar.



Computer with joystick interface

Joystick Interface

All control of your ship is accomplished using a joystick interface. To fire your guns, you must depress the "trigger" located in the top-front button of the control device. Aiming and directional control of your ship is accomplished by wrist movements transmitted by the joystick to the computer. To apply forward and backward thrust, you must use the mouse. Forward motion of the mouse applies forward thrust. Backward motion of the mouse applies backward thrust.

Familiarization period

Prior to beginning the actual simulation, the experimenter will allow you a five-minute familiarization trial period. Use this time to try out all the system functions, especially

those related with ship control, aiming, and firing. After the five-minute familiarization period is over, you will begin the simulation. You will then have three fifteen-minute trials in which to fly the mission.

APPENDIX C

SIMULATION DISCOMFORT SURVEY

ID#______
(last four of SSN)

SIMULATION DISCOMFORT SURVEY

Group A B (circle one) **Platform** A B (Circle one) **Trial** 1 2 3 (circle one)

Please do not write your name on this survey.

We want to evaluate how you feel after you accomplish each trial in the experimental simulation. Your candid responses to the items below will be of great help. For each symptom, circle the rating that applies RIGHT NOW using the following key:

1 = none 3 = moderate
2 = slight 4 = severe

	SYMPTOM	RATING
1.	General discomfort	1 2 3 4
2.	Fatigue	1 2 3 4
3.	Boredom	1 2 3 4
4.	Drowsiness	1 2 3 4
5.	Headache	1 2 3 4
6.	Eye strain	1 2 3 4
7.	Difficulty focusing	1 2 3 4
8.	Dry mouth	1 2 3 4
9.	Excess salivation	1 2 3 4
10.	Cold sweating	1 2 3 4
11.	Nausea	1 2 3 4
12.	Blurred vision	1 2 3 4

13. Other: Please describe: ______________________________

____

____

____

____

____

____

APPENDIX D

SHIP MANEUVERING STRATEGIES TEMPLATE

SHIP MANEUVERING STRATEGIES TEMPLATE

ID#_____ Observer _______
(last four of SSN)

Group A B (circle one) **Platform** A B (circle one) **Trial** 1 2 3 (circle one)

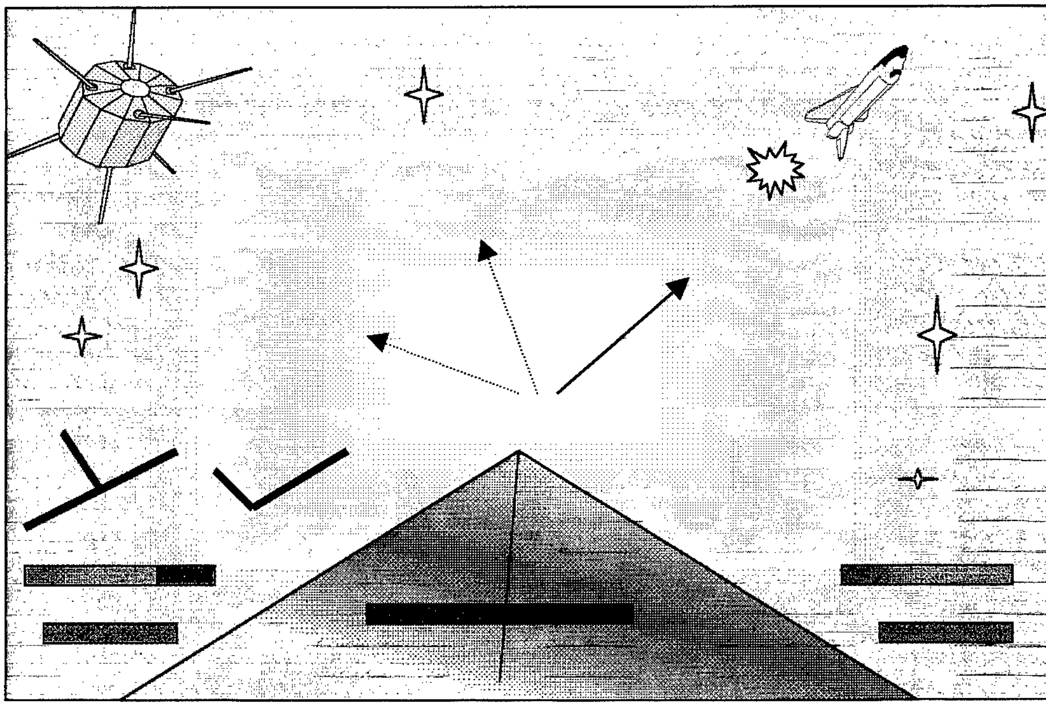
Make a determination of a subject's performance strategy immediately after the subject finishes a trial. If strategy use does not appear to match a recognized strategy, indicate it as "unidentified flight pattern."

Performance Strategy	**Trial 1**	**2**	**3**
Slow Circling. Subjects using this flight pattern demonstrate slow ship movement on the X and Y dimensions. There are very few occasions where the subject's ship wraps around the screen and few movements into the line of fire of the enemy. There is relatively little manipulation of the joystick interface and control inputs are smooth and controlled.			
Rapid Circling. These subjects tend to fly around the screen with relatively high speed. They show a very high level of manipulation of the joystick in both the X and Y dimensions. The result is a high amount of movement in both dimensions on the screen.			
Straight-line flight. The subjects in this group tend to forfeit control of ship acceleration. They choose to give the ship an initial acceleration and from that point on are concerned only with controlling rotation. This pattern is characterized by little manipulation of the control stick interface in the Y dimension and more on the X dimension.			
Unidentified flight pattern. Subjects in this group tend to demonstrate erratic control movements or are not consistent with any particular strategy.			

APPENDIX E

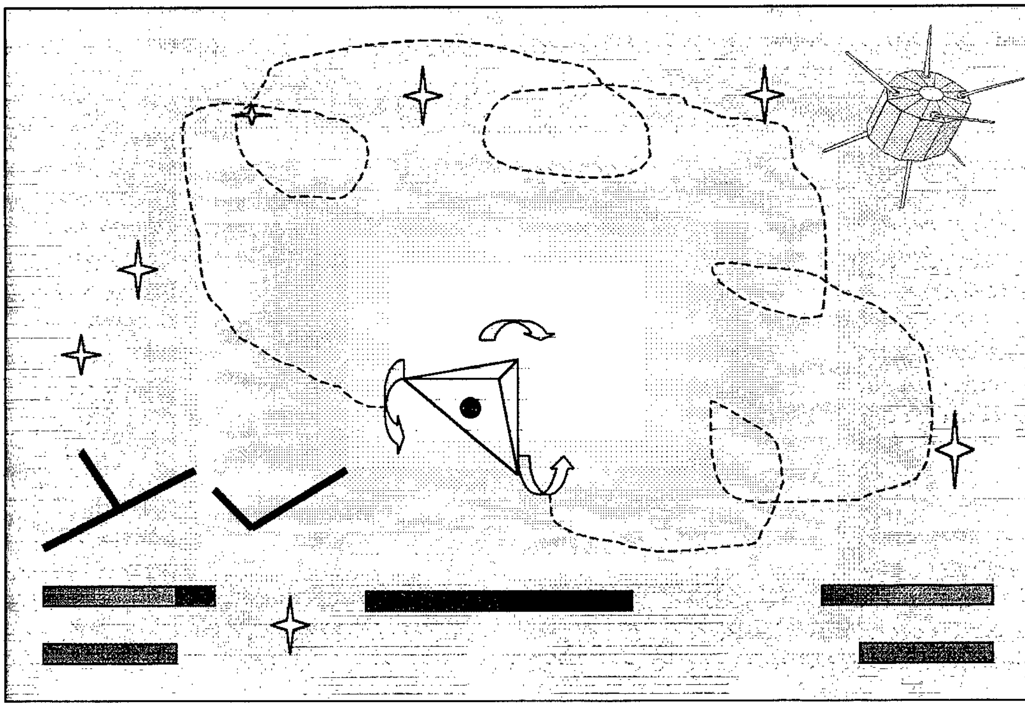
SHIP MANEUVERING STRATEGIES ILLUSTRATIONS

Slow Circling Maneuvering Strategy



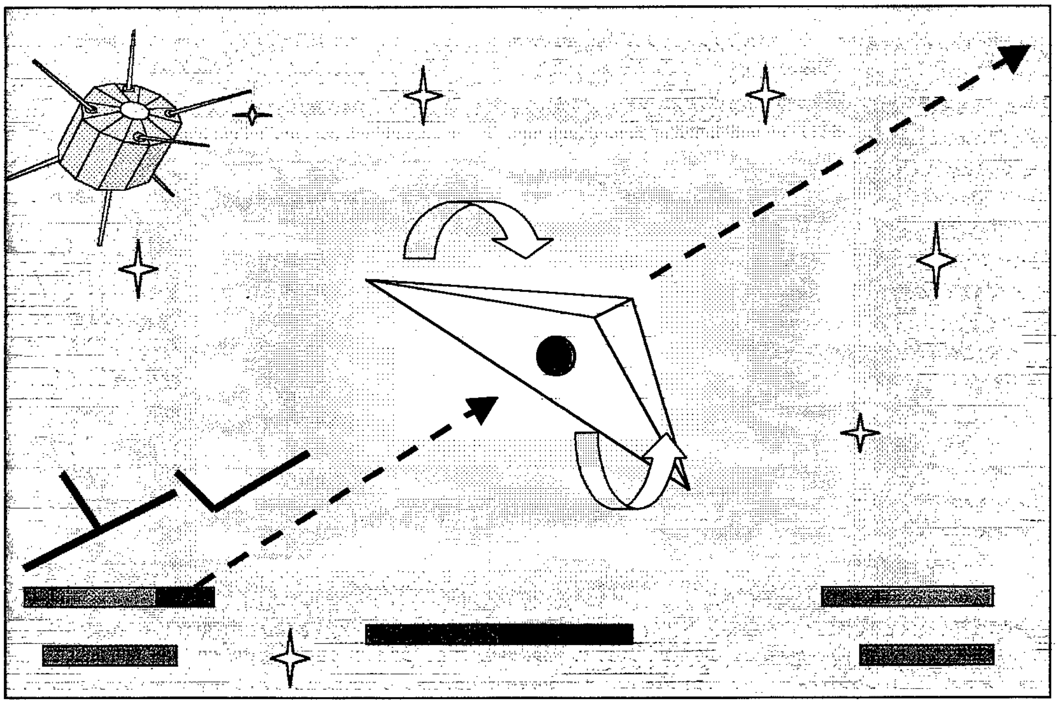
Subjects using this flight pattern demonstrate slow ship movement on the X and Y dimensions. There are very few occasions where the subject's ship wraps around the screen and few movements into the line of fire of the enemy spaceship. There is relatively little manipulation of the joystick interface and control inputs are small and controlled.

Rapid Circling Maneuvering Strategy



These subjects tend to fly around the screen with relatively high speed. They show a very high level of manipulation of the joystick interface in both the X and Y dimensions. The result is a high amount of movement in both dimensions on the screen. Control inputs tend to be large and result in frequent overshooting of intended targets.

Straight-line Flight Maneuvering Strategy



The subjects in this group tend to forfeit control of ship acceleration. They choose to give the ship an initial acceleration and from that point on are concerned only with controlling rotation. This pattern is characterized by little manipulation of the control stick interface in the Y dimension and more on the X dimension. There is little to no manipulation of the throttle with relatively large inputs to the lateral controls.

APPENDIX F

END OF EXPERIMENT QUESTIONNAIRE

ID#_____
(last four of SSN)

END OF EXPERIMENT QUESTIONNAIRE

Group A B (circle one) **Platform** A B (circle one)

Please do not write your name on this survey.

We need to understand other factors that might have influenced your performance in the experimental simulation. Part One of this survey relates to specific display characteristics and Part Two contains statements about your general attitude towards the experimental task.

Part One: Display Characteristics

Circle your responses according to the following key:

1 = Very acceptable
2 = Acceptable
3 = Unacceptable
4 = Very unacceptable

1.	Display resolution (absence of blur, ability to see fine detail)		1	2	3	4
2.	Display brightness		1	2	3	4
3.	Object-to-background contrast in visual scene		1	2	3	4
4.	Uniformity of color		1	2	3	4
5.	Color vividness (absence of washout)		1	2	3	4
6.	Depth cues from visual scene		1	2	3	4
7.	Motion cues from visual scene		1	2	3	4
8.	Image distortion		1	2	3	4
9.	Display noise (visible artifacts that are not part of the original scene)		1	2	3	4
10.	Display ghosting (double images)		1	2	3	4

Part Two: General Attitude

Circle your responses according to the following key:

1 = Strongly agree	3 = Disagree
2 = Agree	4 = Strongly disagree

1.	There was enough practice before the simulation	1	2	3	4
2.	I thought the simulation challenged my skills	1	2	3	4
3.	I was comfortable during the simulation	1	2	3	4
4.	I really felt I was a part of the simulation	1	2	3	4
5.	I tried hard to perform well in the VR space duel	1	2	3	4
6.	I enjoyed the space duel	1	2	3	4
7.	The simulation was about the right length	1	2	3	4
8.	The skills required in the space duel are appropriate for potential Air Force pilots.	1	2	3	4
9.	I wish we practiced these types of skills more often	1	2	3	4
10.	I would like to use other programs similar to this one	1	2	3	4

APPENDIX G

VR SPACE DUEL EQUIPMENT LIST

VR Space Duel Equipment List

Item #1

Description: Virtual I/O PC Version Head-Mounted Display

Technical Specifications:

Optics

- Heads-up distortion free display
- 30 degree field of view (each eye)
- 100% stereo overlap

Displays

- 2 full-color 0.7" Liquid Crystal Displays
- 180,000 pixel resolution

Item #2

Description: Super Warrior Quickshot Joystick

Technical Specifications:

- Auto-centering
- X/Y Axis Adjustments
- High speed Turbofire Capability

Item #3

Description: Packard Bell Legend 422CDT Personal Computer

Technical Specifications:

Monitor

- 14 inch (13 viewable) display
- 400,000 pixel resolution

CPU

- Pentium 133 MHz processor
- 16 MB of RAM

Sound

- 16 bit SRS 3-D Amphitheater Stereo Sound

BIOGRAPHICAL SKETCH

Fernando Manrique was born in Neiva, Colombia, on April 23, 1959. He received his elementary education at the British-Colombian School in Bogota, Colombia. His secondary education was completed at Hargrave Military Academy in Chatham, Virginia. In 1976, Fernando was accepted to The College of William and Mary, Williamsburg, Virginia, majoring in political science. After graduation he was selected for pilot training in the United States Air Force, flying air-refueling tanker aircraft at Kadena Air Base, Japan. In 1990 he was assigned as an instructor pilot to the Air Force's main KC-135 (Boeing 707-717) flight-training school in Merced, California. During this period, he completed the University of Southern California's Systems Management program, earning a master's degree in management. He was then appointed to the faculty of the United States Air Force Academy. Fernando was recognized as the Outstanding Academy Educator in the Department of Foreign Languages for the 94-95 academic year. He was then selected for an Air Force Institute of Technology sponsored Ph.D. program at Arizona State University.